Estimation of Field Maps with Susceptibility Gradient Mapping

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Introduction: A field map can be used to measure field inhomogeneity which provides important information in correcting MR image distortion or tuning an MR system. Traditional method for acquiring a field map is to use two phase maps acquired at different echo times (TE). The field map can be obtained by taking the difference of the two phase maps divided by the difference of the two TEs. In order to do this, phase unwrapping is usually needed to construct a continuous phase map from a wrapped phase map. However, the procedure of phase unwrapping could be very problematic as errors occur frequently due to inconsistent data in the wrapped phase map and unavoidable noise. Since phase is represented by its principal values between [$-\pi, \pi$], reliable phase unwrapping algorithms are required to get the accurate phase information. In this study, it is shown that the Susceptibility Gradient Mapping (SGM) [1] method for positive contrast imaging can be used to get a field map without a phase unwrapping procedure.

Theory: Conventional field maps can be obtained using the following equation, $\varphi(TE2)-\varphi(TE1)/ (TE2 - TE1)= \omega_0 + \Delta\omega_0 = \omega$, where ω_0 is the frequency due to B_0 and $\Delta\omega_0$ is the frequency due to ΔB_0. For simplicity, one can ignore ω_0 and just focus on measuring the $\Delta\omega_0$ (or $\Delta B_0= \Delta\omega_0 / \gamma$) by using the phase changes in the image space, where $\Delta\omega_0$ is generated by additional gradient G_{add} induced by susceptibility difference (other than the designed imaging gradient).,The SGM method [1] was originally proposed for positive contrast imaging of iron-oxides contrast agents. It measures the echo shift k_0 in the K space in order to detect the additional gradient G_{add} [2], $G_{add} \approx -k_0 \cdot G_{imaging} \cdot \tau_i \cdot TE^{-1}$, where τ_i represents the gradient duration. It was noticed that both the field map and SGM method actually measure the same physical quantity G_{add}. In fact, the image space and k space is related by the Fourier transformation. The shift theorem [3] of the Fourier transformation ($F^{-1}\{ S(k-k_0) \} = \exp(i2\pi k_0 x)\, F^{-1}\{S(k)\}$) tells that shift k_0 in the k space causes the phase change $\Delta\varphi = 2\pi k_0 x$ in the image space which indicate the equivalence of the field map and SGM method.

Data Acquisition and Results: Experimental MR measurements were taken using a 3.0 T GE SIGNA HDX MR scanner (GE Medical Systems, Milwaukee, WI). Gradient refocused echo (GRE) scans were taken on the human brain with TE=6 ms and TE = 7.5 ms, TR = 150 ms, flip angle = 90 degree, slice spacing = 8 mm, thickness= 4mm, image matrix=128 x 128. Field maps were generated using the two phase map difference and the SGM method, respectively, which are shown in Figure 1. The top row presents the field map of an inferior axial slice, and the bottom row shows a superior axial slice. The first and second columns demonstrate the k_0 shift in the x and y direction, and the third column presents the field map generated by difference of two phase maps. It is seen that the field maps generated by SGM (panels a, b, d, and e in Figure 1) preserves all the details of susceptibility-induced inhomogeneity (with a scaling factor) but does not present any field discontinuity, as seen often in field maps generated by differences of two phase maps. On the other hand, wrapped phase in the traditional field map (panels c and f in Figure 1) appears as a discontinuity in the image which requires a phase unwrapping process.

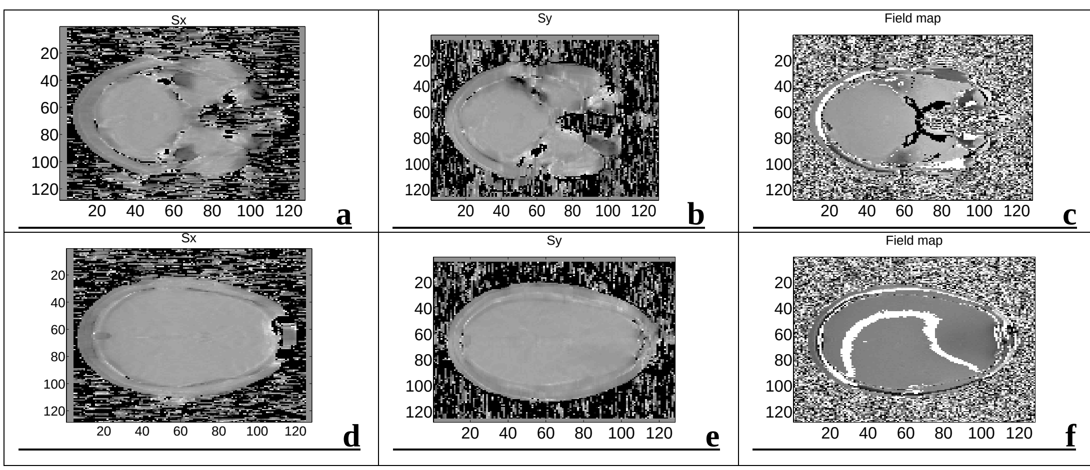

Figure. Field maps generated with SGM method (the first and second columns) and traditional method of difference of two phase maps without unwrapping (the third column). The upper row shows an inferior axial slice and the lower row shows a superior slice. Panels a & d: SGM map for the k_0 shift in the x direction; b & e: SGM map for the k_0 shift in the y direction; c &,f: conventional field map without unwrapping.

Discussion: The SGM method was employed in this study for estimating a field map. The shift theorem of Fourier Transform shows that the SGM map and field map are equivalent with some proportional constant. Compared with traditional methods of acquiring a field map that needs two phase maps at two different TEs, only one phase map acquired with a single TE is required by the SGM method to generate a field map. Furthermore, the SGM method does not require any phase unwrapping algorithm. Future work will be focused on improvement of estimate of the k_0 shift and generation of a three-dimensional map with a single 3D data acquisition.

Reference:

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