Background Field Removal through Infinite Spherical Mean Value Operation

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INTRODUCTION. An accurate local field map is the basis of an accurate magnetic susceptibility map, which is useful for studying various physiological and pathological conditions [1]. There are two schools of approaches to remove the background field, either by dipole fitting such as iterative dipole fitting (PDF) [2], or by utilizing the spherical mean value (SMV) property such as Sophisticated Harmonic Artifact Reduction on Phase Data (SHARP) [3]. However, SHARP involves careful selections of processing parameters including the radius of the sphere R and a truncation threshold in its deconvolution step, both of which have non-negligible effect on the results but the selection criteria is empirical. Here, we combine the iterative aspect of PDF with the SMV principle to form an infinite SMV (iSMV) method that eliminates the deconvolution and significantly reduce the dependence on radius.

THEORY. The field inhomogeneity ψ measured in a certain region of interest consists of a background field ψ_h, which is a harmonic function, and a local field ψ_{nh}, which is a non-harmonic function, and $\psi = \psi_h + \psi_{nh}$. Taking the mean value over a solid or hollow sphere S of the field map could be expressed as $S \otimes \psi$ with $\otimes$ denoting convolution. If this operation is repeated infinite many times, then $S^{\infty} \otimes \psi = S^{\infty} \otimes \psi_h + S^{\infty} \otimes \psi_{nh} = \psi_h + S^{\infty} \otimes \psi_{nh}$ by invoking the distributive law of convolution and SMV property of harmonic functions[4]. It is further noted that ψ_{nh} is non-zero only in a finite range, so it can be proven that $S^{\infty} \otimes \psi_{nh} = 0$. Thus, the background field can be eliminated from the field map by $\psi - S^{\infty} \otimes \psi = (\psi_h + \psi_{nh}) - (\psi_h + 0) = \psi_{nh}$, and the local field is obtained.

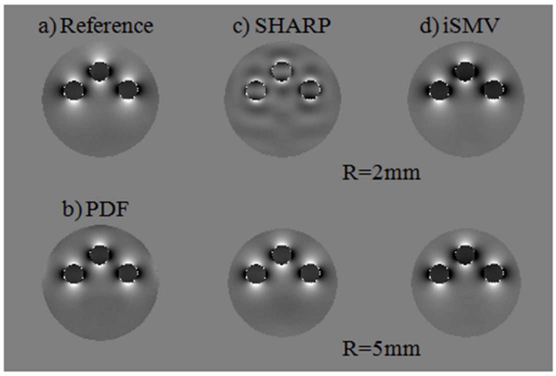

Fig. 1. A) Reference; b) PDF; c) SHARP with different radii, threshold=.05; d) iSMV with different radii.

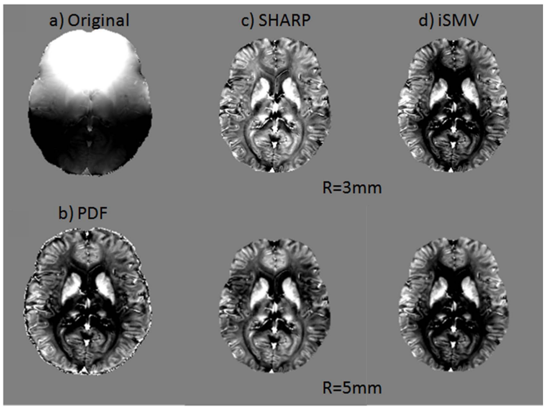

Fig. 2. a) Original field map; b) PDF; c) SHARP with R=3&5mm, threshold=.05; d) iSMV with R=3&5mm.

MATERIAL AND METHODS. *Phantom Validation:* A water phantom containing three vials of 1% Gadolinium solutions were scanned using 3D gradient echo sequence (TE/TR/FA/BW = 1.7, 2.2, 4.2 and 14.2 ms/30ms/30°/±62.50 kHz) on a 1.5-T scanner (GE Excite HD; GE Healthcare, Waukesha, WI, USA) using a 5-in surface coil for signal reception. Afterwards, the three vials were removed and the remaining structures were scanned for a reference background field [2]. *Human subjects:* Five healthy volunteers were scanned using a 3D multi gradient echo sequence (TE/ΔTE/#TE = 5ms/5ms/8, TR/FA/BW=50ms/20°/±62.50 kHz) on a 3T scanner (GE Excite HD) to assess the performance of background field removal. *Data Processing:* The proposed method is implemented as an iterative filtering processed. In each iteration, the field map F^n is updated from previous field map F^{n-1} by $F^n = M_R \cdot (S \otimes F^{n-1}) + (M - M_R) \cdot F^0$, where M is the original mask, M_R is M eroded R millimeters from the boundary, and F^0 is the original field map. Local field was obtained as $F^0 - F^{\infty}$, and the results were compared with reference standard in phantom experiment and with SHARP and PDF in all data. Different radii were applied to evaluate their influences on the results. The smallest radius was chosen as the smallest integer that is greater than slice thickness.

RESULTS. The phantom results were shown in Fig. 1, where PDF local field (Fig. 1b) showed high degree of similarity with reference standard (Fig. 1a, relative error=6.2%), but error on SHARP varied with radii (Fig. 1c, relative error=15.0% when R=2mm, relative error=6.1% when R=5mm), and there was a loss of contrast when R=2mm. This loss of contrast was repaired in the iSMV method (Fig. 1d, relative error<5% in both). An exemplary human subject is shown in Fig. 2, while the contrast of the local field obtained from SHARP (Figs. 2c) increased with an increasing R compared to the PDF local field (Fig. 2b), iSMV reduced the dependence on R, presenting a more consistent local field (Fig.2d) which also resembles the one from PDF.

DISCUSSION AND CONCLUSION. Our results showed that when the radius is small, there was a loss of contrast on SHARP results. This may be caused by the digitized SMV kernel employed in SHARP, which severely deviated from a true sphere when only a few discrete voxels were used. This problem is alleviated in iSMV where small spherical kernel is repeatedly applied to the field map, effectively acting as a large kernel. Thus, the iSMV method allowed the use of a small kernel to retain large region of interest while keeping the local field contrast. Furthermore, it completely bypassed the deconvolution step, reducing potential inconsistency caused by arbitrary thresholds.

REFERENCE

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