Synthesis of Multiple Phase Cycled SSFP Images to remove band artifacts as well as to improve the SNR By Use of a Spectral Decomposition

K-J. Jung[1,2]

[1]Brain Imaging Research Center, Univ. of Pittsburgh & Carnegie Mellon Univ., Pittsburgh, PA, United States, [2]Bioengineering Department, University of Pittsburgh, Pittsburgh, PA, United States

Introduction: The dark band artifacts are the major obstacle in SSFP even though the fast imaging with higher signal and strong T2 contrast is very promising for the structural and fMRI imaging[1,2]. From the multiple acquisitions of phase cycled SSFP the MIP (maximum intensity projection) can effectively remove the band artifacts. In spite of combining multiple images., however, it does not improve the SNR. Two methods, i.e., complex summation[3] and SoS (sum-of-square)[4], had been reported to achieve both objectives. These methods, however, could not be experimentally confirmed to be effective in removing the band artifacts. Therefore, a new method has been developed to remove the band artifacts while improving the SNR through averaging the multiple images.

Methods: The width of the band artifacts is usually over several pixels and the image intensity varies more slowly relative to the random Gaussian noise in general. Therefore, the band artifacts can be spectrally separated into a lower frequency component from the random noise by use of the spectral decomposition. Since MIP is very effective in removing the band artifacts, the lower spectral component of each acquisition can be combined through MIP (Fig. 1). On the other hand, the high frequency component of each acquisition can be averaged to improve the SNR. Then, the low and high frequency components are summed to produce the output image. This method will remove the band artifacts by MIP while improving the SNR through the averaging. The images were obtained at 3T for both a phantom and a human head (sagittal orientation) by use of the TruFISP sequence with four different schemes of phase cycling, i.e., $\Delta\Phi$=0°, 90°, 180° and 270°. The magnetic field was shimmed by the scanner's default tuning procedure. A 2-dimensional Gaussian filter was used for the LPF (low pass filtering). The HPF (high pass filtering) was obtained by [1 – LPF]. The proposed method was compared with other methods.

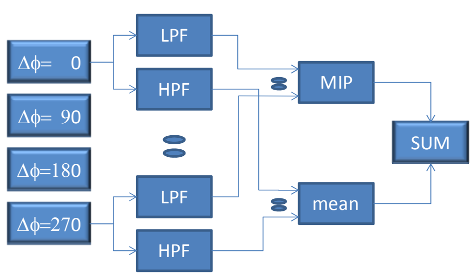

Fig. 1. A block diagram of the image summation based on the spectral decomposition.

Results: As expected, the band artifacts appeared on both the phantom and head images and their locations varied by phase cycling schemes without overlapping (Fig. 2). The MIP result of the LPF images was free from the band artifacts. The average of the HPF images included most of edges (Fig. 3). The conventional and the proposed methods were compared as shown in Fig. 4. The proposed method was compatible with MIP in removing the band artifacts. The proposed method (background mean = 50) had a less mean signal than MIP (background mean = 62), but was larger than the mean image (background mean = 42) in the background. On the other hand, the complex sum and SoS were only slightly better than the mean in removing the band artifacts. Besides, the complex sum suffered from the destructive cancellation due to the phase distribution over the multiple phase cycled images.

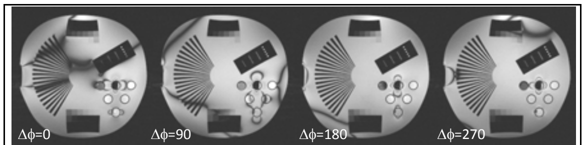

Fig. 2. Phantom images of four phase cycling schemes.

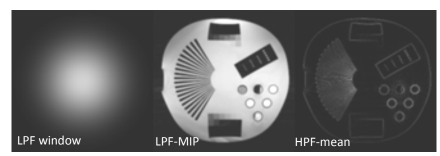

Fig. 3. Spectral decomposition of phantom images.

The phantom results were reproduced at the head imaging (Fig. 5). There was a typical band artifact in the image of $\Delta\phi$ = 180° (region 2 in Fig. 5A). The performance of the proposed method were compared with other methods through the measurement of the mean image intensities of three regions marked in Fig. 5A: 1) the high image intensity region in the middle, 2) the band artifacts region, 3) background. The results are summarized in Table 1. As known, the MIP was most effective in removing the band artifacts and the proposed method was very close to MIP. In addition, the proposed method was able to suppress the background noise better than MIP. Both the complex sum and SoS methods, however, did not significantly reduce the band artifacts compared to the mean method. Besides, the complex sum suffered from the signal reduction due to the destructive phase interference. The proposed method was also effective for two sets of phase cycled images. In conclusion, the proposed method can achieve the performance level of MIP in removing the band artifacts, and restore most of the averaging effect in improving the SNR (signal-to-noise-ratio). On the other hand, the published methods of complex sum and SoS were found to be ineffective in removing the band artifacts. Since the proposed method is effective for 2 sets of phase cycling in removing the band artifacts, it could restore the fast imaging feature of SSFP by acquiring only two sets of phase cycling instead of four sets.

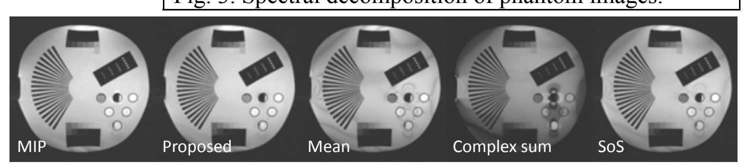

Fig. 4. Syntheses of four phase cycled phantom images.

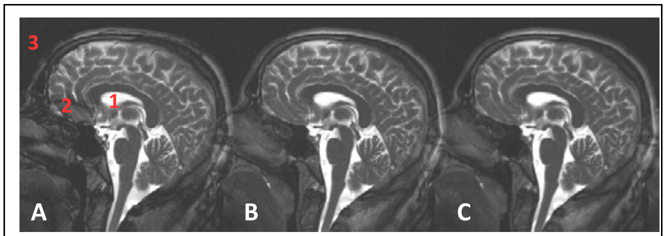

Fig. 5. Head images. (A) The base image at $\Delta\phi$=180. (B and C) Images from MIP and the proposed method, respectively. The red numbers in (A) denote the ROIs for the image intensity analysis.

ROI	1	2	3
$\Delta\phi$=180	84	0	69
MIP	100	100	100
Mean	76	64	60
Complex	58	30	30
SoS	79	70	67
Proposed	100	96	78

Table 1. Comparison of average image intensities relative to MIP for the three ROIs. Unit = %.

References: 1. Haacke EM, et al., Radiology 1990;175(2):545-552. 2. Zur Y, et al., Magn Reson Med 1990;16(3):444-459. 3. Vasanawala SS, et al., Magn Reson Med 2000;43(1):82-90. 4. Bangerter NK, et al., Magn Reson Med 2004;51(5):1038-1047.