The Essence of Half-FOV Shift Ghost Imaging

L. ZHA[1], and M. Miyazaki[1]
[1]Toshiba Medical Research Institute USA, Vernon Hills, IL, United States

Introduction: Ghost imaging and especially its applications to MR angiography (MRA) have been proposed as an improvement over the conventional magnitude subtraction based imaging methods, such as Fresh Blood Imaging (FBI) [1]. There are basically two types of ghost MRA; type I and II. Type I is usually performed without gating, by summing outside the body ghost artifacts created from uncontrolled variations of flow and other natural phenomena that are shifted pseudo-randomly in distance along a single direction perpendicular to the direction of ghost generation [2-3]. Type II aims to create controlled flow-induced changes between the even and the odd *k*-space lines, to create systematically controlled ½ FOV shifts, which projects as a 3D ghost differential image outside the body, that can be maximum intensity projection (MIP) processed along multiple angles [4]-[7]. The latter was reported to show superior background suppression and allowed higher parallel imaging acceleration factors.

Method and Simulation Result: We investigated the type II ghost formation mechanism, and explored the hypothesis that ghost imaging is just another form of complex subtraction imaging in the essence. The differential vector matrix between arbitrary even and odd subsets of *k*-space complex data can always be decomposed into two components, one with a 180° phase alternating between the even and odd *k*-space lines, and one without. The alternating components are shifted by ½ FOV after Fourier transformed (FT), while the identical component is not shifted.

To confirm the mechanism, we conducted MatLab simulations with synthesized phantom image data, with systematically changing even and odd *k*-space line magnitude and phase differences dI and $d\phi$, so that all the odd line signal were multiplied by a factor I_o, which is the even line multiplication factor I_e multiplied by a factor $I_o=I_e\, dI\, \exp(i\, d\phi)$, where $dI=(I_o/I_e)$. The chart below shows numerically the ghost imaging magnitude is just $I_{ghost} = |\, I_e\, [1-dI\, \exp(i\, d\phi)]\, |$, which is exactly the same as direct complex subtraction, $|I_e - I_o|$.

Examples of Experimental Results: We also acquired sets of non-contrast FBI MRA imaging data of thighs on a prototype Toshiba Vantage 3T system with systolic and diastolic cardiac gating delays, with the phase encoding (PE) FOV and PE matrix size both doubled from the normal values to allow the space for ghost formation. The even *k*-space lines were extracted from the raw data set of systole cardiac phase, and the odd lines from the diastole phase, to form new data sets of halved size (that produces normal PE FOV), as well as the ghost imaging data from interleaving them.

The resulting reconstructed MIP ghost MRA image is shown (top left, cropped so only the ghost half remains) along with that from complex subtraction (top right). The differential image (bottom left, intensity scaled up 30 times) shows the ghost and complex subtraction images are virtually the same, both with somewhat cleaner background subtraction than the magnitude subtraction MIP image (bottom right).

Ghost Image Intensity over Even/Odd Line Magnitude(I) & Phase (Phi) Changes
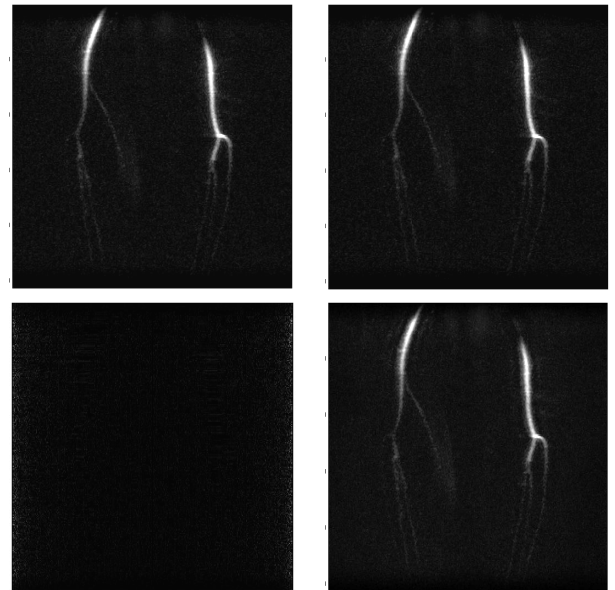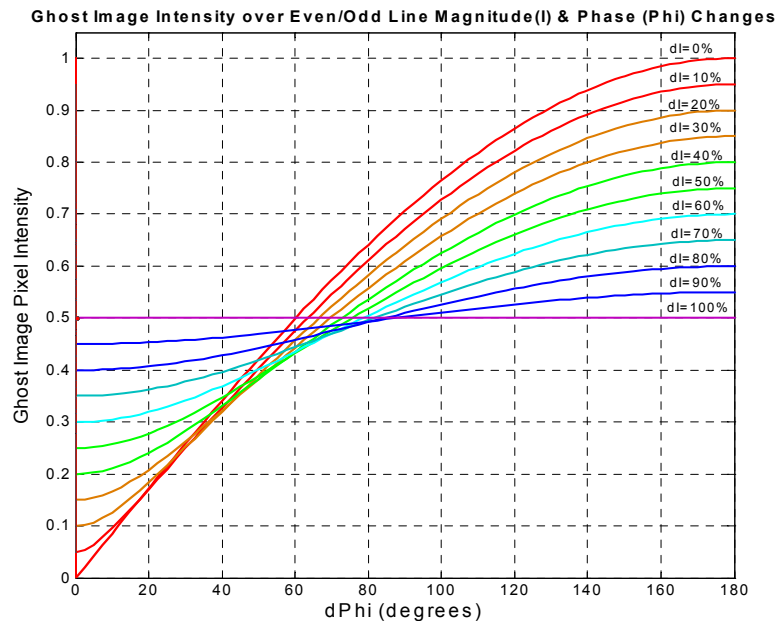
Discussions: It is usually difficult to create real uncontaminated complex subtraction images, from the very existence of common raw data manipulations, such as echo centering and filtering and corrections of various kinds. Thus, ghost imaging provides an easy and valuable walk-around scheme in obtaining often superior complex subtraction results as reported [8]. The scan time remains the same as the subtraction imaging, since the PE encoding matrix size is twice. However, one often needs to be extra careful to first eliminate any uncontrolled background ghosting artifacts from the intended ghost formation region, which are not from the purposely introduced contrast generating mechanism between the even and the odd lines.

References:
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