Mitigating Vibration Related Image Shading in Diffusion Weighted Imaging with Adaptive Homodyne Reconstruction

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INTRODUCTION

Partial Fourier (PF) imaging is often used in diffusion weighted echo planar imaging (DW-EPI) to minimize echo time and maximize signal-to-noise ratio. The most commonly used PF reconstruction method is homodyne processing [1], which uses several center k-space lines to estimate a low resolution phase map and apply that phase map in conjunction with Fourier conjugate symmetry to reconstruct the missing k-space lines and final image. Homodyne processing is advantageous over an alternative zero filling approach in that it retains the desired image resolution. However, DW-EPI is known to be sensitive to subject motion and eddy currents due to the large DW gradients often used; both motion and eddy current could generate k-space center shift, broadening, or other degradation, leading to poorly estimated phase map in homodyne reconstruction and the subsequent image artifacts (e.g., worm-like artifact or shading). A method based on intensity peak [2] and another method based on k-space energy spectrum analysis [3] were previously proposed to adjust the k-space window to track the true k-space center, therefore reducing the artifacts due to subject motion and eddy currents, respectively. Occasionally, image shading artifacts can also appear due to gradient induced table vibration. In this paper, we show that a simple method similar to Refs [2,3] to adaptively choose homodyne lowpass window based on the k-space centroid can also be applied to reduce the image shading artifacts.

METHODS

A set of PF DW-EPI data was acquired with an 8-channel brain coil on a 3T GE scanner where the patient table bridge was well separated from the body coil to minimize vibration. Data with diffusion directions respectively on X, Y, and Z axes were collected with 128×128 matrix size. Other related imaging parameters were: TR = 6.7 s, 60 slices, 16 overscan lines, b = 1000 s/mm^2. The k-space center matches well with its expected location for data of all three diffusion directions; only the DW-Z-axis k-space data is shown in Fig. 1a for illustration purpose where the red bounding box is the expected center k-space lines used in homodyne reconstruction. For comparison, we inserted wooden wedges between the table bridge and the body coil to induce vibration into the patient table. The resulting DW-Z-axis k-space data is shown in Fig. 1b, where we see 1) the k-space center is shifted from the expected location (red dotted bounding box) and 2) the k-space energy is more dispersed than the data without vibration. This k-space data was then reconstructed by four different PF methods for comparison: homodyne [1], iterative homodyne [4], zero filling, and adaptive homodyne where we have used the k-space centroid to adaptively choose the homodyne lowpass window location (green solid box in Fig. 1b, which better encompass the true center k-space lines) and slightly increase the transition width of the window (shown as a wider green box than the red box).

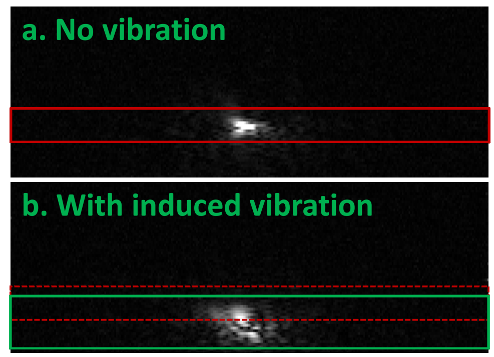

Fig. 1. Comparison of partial k-space data from a DWI experiment a) without patient table vibration and b) with table vibration induced by inserting wooden wedges between the table bridge and the body coil.

RESULTS

Figure 2 shows a representative slice of the brain DW-Z-axis images from the four PF reconstruction algorithms mentioned in the Methods section. The standard homodyne reconstruction generates large shading at one corner of the image (marked by the red arrow) due to the poorly estimated phase based on the data in the red dotted bounding box of Fig. 1b. Although iterative homodyne was previously shown capable of progressively correcting inaccuracies in the phase map over iterations, it essentially still uses the same, suboptimal k-space lines in the red box of Fig. 1b. For this particular dataset, the shift and degradation of k-space data are significant enough that iterative homodyne is incapable of reducing the shading artifacts over the standard homodyne algorithm. The zero-filling reconstruction does not have the shading issue because it does not need to estimate any phase map from the data (hence insensitive to k-space shift). However, the zero-filling reconstruction shows the expected, undesired image blurring. The adaptive homodyne retains image resolution and removes the image shading. This is because the homodyne phase map is much more accurately estimated from the adaptively selected window (green box in Fig. 1b) than in the standard homodyne reconstruction.

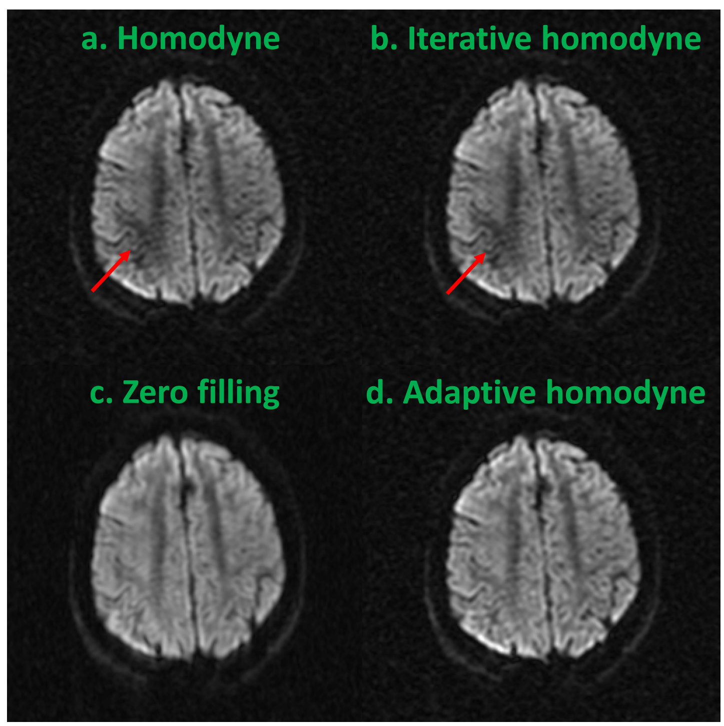

Fig. 2. DW-EPI images from the k-space data shown in Fig. 1b by four different partial Fourier reconstruction algorithms. The adaptive homodyne algorithm removes the shading shown in the standard and iterative homodyne reconstructions (marked by the red arrows) while avoiding image blurring seen in the zero filling reconstruction.

CONCLUSIONS

Subject motion and eddy currents were previously shown to cause worm-like or shading artifacts in DW-EPI images reconstructed by homodyne processing. In this paper, we have shown that gradient induced table vibration can also cause the shading artifacts. By adaptively choosing the homodyne lowpass window location and width using a k-space centroid based method, the shading artifact can be effectively mitigated. This method can make DW-EPI image reconstruction less sensitive to k-space shift/degradations in general.

REFERENCES

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