A Six Degree of Freedom Motion Correction Algorithm for 3D MR Imaging

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Introduction

Motion during magnetic resonance imaging causes image blurring and ghosting artifacts. A number of investigators have proposed methods for correcting these motion artifacts in two-dimensional MR images based on averaging and phase corrections derived from image parameters or navigator echoes [1-2]. However, for three arbitrary 6 degree-of-freedom motions through-plane motion correction is needed thus requiring volumetric data acquisitions. One solution to this problem is based on real-time alteration of scan plane parameters through object position measures achieved from navigator echoes, but requires additional modifications to the pulse sequence and therefore added scan time overhead [3]. Alternatively, we demonstrate the use of external motion tracking data that is used to provide the required alterations in k-space data for motion compensation that can be applied to any volumetric MR acquisition. This technique is subject to the assumption of rigid body motions but is particularly well suited to applications where tracking superficial anatomy is likely to meet this requirement. An example in point, would be the volumetric imaging of bilateral breast MRI with the patient in a supine geometry where respiration artifacts are likely to be severe. In this application, breast MRI is more applicable to pre-surgical planning that would be feasible by standard prone breast MRI.

Methods

The technique was simulated through a set of static 3D MR images (128x128x128) of an agar phantom containing various structures of high contrast. Data was acquired on a GE 3T MR scanner (fSPGR, TE/TR/angle=2.9ms/7.7ms/30^{o}) as shown in Fig. 1a. The effect of object motion was introduced through a 6 degree-of-freedom (3 positions, 3 angles), ranging from 10-40 degrees distributed among the 3 rotation axes and 10-40 mm of translation distributed among the 3 Cartesian axes. This was introduced on the k-space data as phase and angular deviations corresponding to the timing of induced motion. This resultant k-space data was then re-gridded onto a Cartesian volume for Fourier transform. The resulting images with reflecting these motion-induced artifacts are shown in Figure 1b. A simulated record of the motion tracking data was then used to compensate for this re-gridded data to remove the corresponding k-space errors, by again doing a second re-gridding to their proper orientations and phase relations. This was done with a Kaiser-Bessel convolution [4] with adjustable window width parameter. The irregular k-space data after correction would have non-uniform density, which was corrected with a 3-D Voronoi volume weighting function similar to the 2-D Voronoi area concept [5]. A range of Kaiser-Bessel convolution window widths W ranging from 2 to 4 were tested.

Results

The effect of the six degree-of-freedom motion is shown to severely degrade the image data (Figure 1b) with considerable ghosting and loss of resolution throughout the image. The effects of motion compensation are shown in Figures 2a&b with a Kaiser-Bessel convolution window width of W=2 and W=4 respectively. This showed that the images could be restored to varying degrees depending on the window width. With a convolution window width of 2, considerable side-lobe energy was seen to remain, which generated ringing artifacts from high contrast structures and non-uniform image contrast throughout the homogeneous portions of the phantom. However, increasing the convolution width to 4, the artifact was substantially reduced with the resulting image very nearly reflecting the original motion free phantom. The correction algorithm took 5-40 minutes depending on the size of the re-gridding kernel using MatLab scripts. These data show that motion compensation can be virtually eliminated with negligible degradation to image resolution.

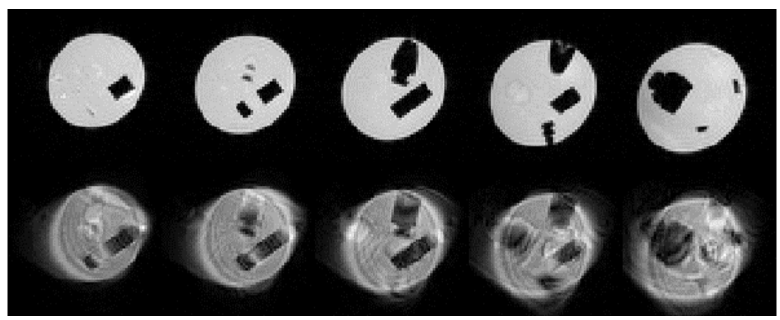

Fig. 1a *(top row). Five images selected from the central region of the static phantom.* ***Fig. 1b*** *(bottom row). Motion corrupted images.*

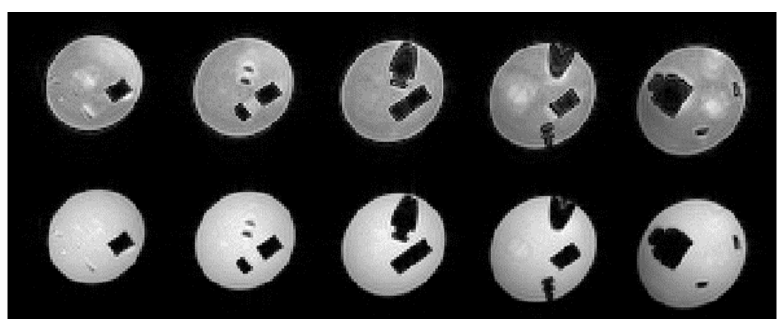

Fig. 2a *(top row). Motion corrected images with Kaiser-Bessel window width W=2 during regrinding process.* ***Fig. 2b*** *(bottom row). Same images obtained with W=4. The images are clearly smoother and ringing artifact was greatly reduced.*

Discussion and Conclusion

These results demonstrate a robust motion correction algorithm for 3D MR image restoration. The results showed that the Kaiser-Bessel functions were effective. The choice of re-gridding parameters is critical to balance ringing and homogeneity of the final images. We propose to apply this to motion compensated breast MRI for pre-surgical applications with an external tracking system.

References

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