Reduction of Under-sampling Artifacts in Radial Scanning by Using k-Space-Data Interpolation

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Introduction

Radial scanning has recently been widely applied for cardiac imaging. In this scanning, fewer artifacts are caused by subject motion than that in the case of a Cartesian scanning. Moreover, increasing temporal resolution by reducing the number of echoes—that is, using under-sampled data—does not reduce image quality as in a Cartesian scanning. However, it often happens that streak artifacts caused by using the under-sampled data become a problem. In light of these issues, the authors have developed a method that can interpolate k-space data so that the streak artifacts are suppressed. The method additionally acquires reference echoes, which are used to calculate weights for the interpolation. A similar method has been demonstrated for parallel radial imaging [1]; however, the present study showed that interpolation of k-space data using reference echoes is an effective way to suppress the under-sampling artifacts in conventional non-parallel imaging. Images obtained by a computer simulation were used to demonstrate that this interpolation reduces under-sampling artifacts without loss of spatial resolution.

Method

The k-space used in the proposed method is schematically shown in Fig. 1. Unacquired missing echoes are estimated by using weights derived from additionally acquired reference echoes (r1, r2, …), and then an image is reconstructed by gridding and fast Fourier transformation. The reference echoes are equally spaced in k-space. The unacquired echoes are divided into groups (b1, b2, …) and there is one reference echo per group. Weights for estimation of the unacquired echoes in each group are calculated using the reference echoes belonging to the group and two echoes adjacent to the reference echo as given in the following equations: $A = RS^{-}$, where $A = [a_1, a_2]$ is a weight, $R = [r_1, r_2, \cdots, r_N]$ is a reference echo, $S = \begin{bmatrix} s_{11}, s_{12}, \cdots, s_{1N} \\ s_{21}, s_{22}, \cdots, s_{2N} \end{bmatrix}$ includes two echoes adjacent to the reference echo R, N is a number of sampled points and S^{-} is a pseudo-inverse of S. Each unacquired echo is then estimated using the weights and two sampled echoes adjacent to the unacquired echo as given in the following equations: $S_u = AS'$, where $S_u = [s_1, s_2, \cdots, s_N]$ is an estimated echo and $S' = \begin{bmatrix} s'_{11}, s'_{12}, \cdots, s'_{1N} \\ s'_{21}, s'_{22}, \cdots, s'_{2N} \end{bmatrix}$ includes two echoes adjacent to the missing echo. In the process of calculating weights and estimating unacquired echoes, each echo is divided into seven parts, and the process is applied to each part separately.

Under-sampled k-space data was acquired using a computer simulation with a subject model composed of ellipses and slits. The subject model was located off-centered in the FOV to evaluate the method properly. The number of echoes was 64, each with 128 samples, and eight additional reference echoes were obtained. Each echo with 128 samples is divided into seven parts. The missing 56 echoes were estimated by the proposed method, and an image with a matrix size of 128x128 was reconstructed by gridding and fast Fourier transformation.

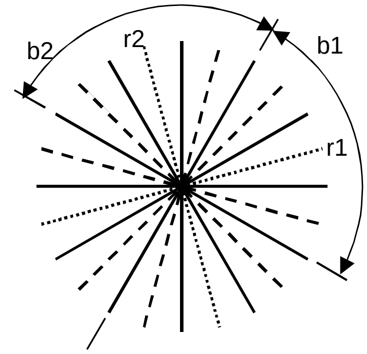


Figure 1: K-space of the proposed method. Acquired echoes, reference echoes and unacquired echoes are shown by solid line, small dotted line, and dashed line, respectively

Results and Discussion

Figure 2 shows the 128 projections derived from echoes estimated by using the proposed method (left) and from fully sampled data (right). The left figure, compared to the right one, shows that the method successfully interpolates the missing echoes.

Figure 3(a) shows the image reconstructed from 72 scanned echoes and 56 echoes estimated by the proposed method, and (b) shows, for comparison, the image reconstructed from 64 scanned projections and 64 projections derived from linear interpolation of the scanned projections. Figures 3(c) and (d) show the images from under-sampled and fully sampled data, respectively.

Comparison of Fig. 3(a) and (c) shows that the proposed method successfully suppresses the streak artifacts; moreover it increases the spatial resolution a little. On the contrary, as shown in Fig. 3(b), linear interpolation reduces the spatial resolution and cannot sufficiently suppress the streak artifacts. In addition, the number of reference echoes used by the proposed method should be more than eight, since less reference echoes would result in lower spatial resolution.

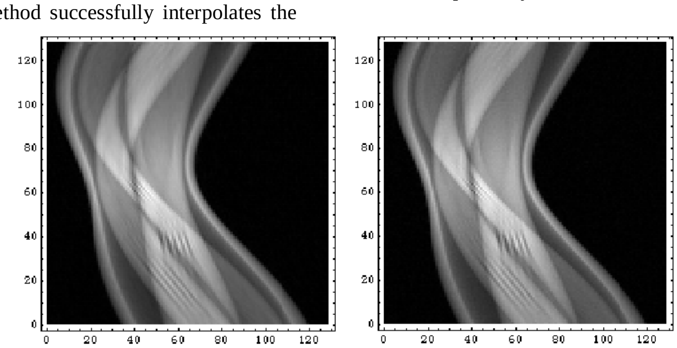


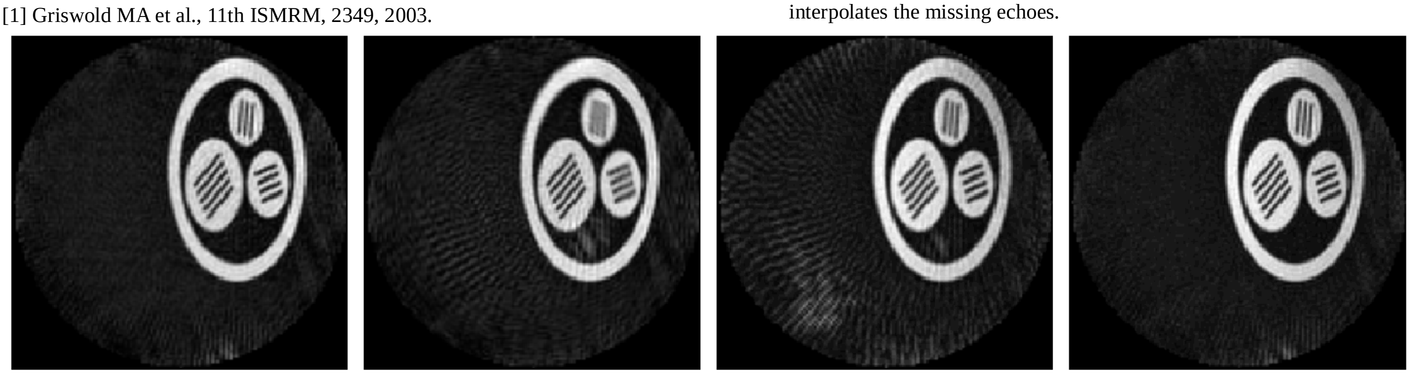
Figure 2: Projections derived from sampled echoes and echoes estimated using proposed method (left) and fully sampled data (right). Vertical direction denotes θ. It is shown that the proposed method successfully interpolates the missing echoes.

Conclusion

The results of a computer simulation have shown that the proposed method for interpolation of k-space data using reference echoes is an easy-to-use and effective way to suppress under-sampling artifacts.

References

[1] Griswold MA et al., 11th ISMRM, 2349, 2003.



(a) proposed method (64+8 echoes) (b) linear interpolation (64 echoes) (c) under-sampled image (64 echoes) (d) fully sampled image (128 echoes)

Figure 3: Reconstructed images