Rapid Retrospective Non-Rigid Motion Correction for Free-Breathing MRI

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Introduction

Navigator echo can detect respiratory motion by detecting the diaphragm position of free-breathing patients. Acceptance window of navigator data enables navigator-gated imaging with considerably less motion artifacts. However, its acceptance rate is around 30% for high-quality images, which results in long scan time. There are many ideas on retrospective motion correction to raise the acceptance rate. In addition to rigid or affine motion correction, non-rigid motion correction (such as GRICS) was proposed recently [1]. Yet it needs long reconstruction time. In this work, we propose a new framework that enables not only non-rigid motion correction with 100% acceptance rate but also rapid reconstruction.

Theory

The motion just before each data acquisition modulates the encoding function from Fourier kernel as

$$S(k_x,k_y)=\sum_{x',y'}K(k_x,k_y;x',y')\sum_{x,y}M(k_y;x',y';x,y)I(x,y)=\sum_{x,y}K'(k_x,k_y;x,y)I(x,y)$$

where S, K, M, and I mean k-space Signal, Fourier transformation Kernel, Motion matrix at each data acquisition, and object Image, respectively. So K' can be called as Motion-Modified Fourier Kernel (MMFK), and the product of S and the inverse of K' provides a motionless image. Here, we call this scheme as MMFK method. All we should know for non-rigid motion correction is to estimate the motion at each data acquisition, which can be done, for example, by navigator echo with motion model.

When the non-rigid motion is restricted to the frequency direction x, the previous equation is modified:

$$S(k_x,k_y)=\sum_{x',y}K_x(k_x;x')K_y(k_y;y)\sum_{x}M(k_y;x';x)I(x,y)=\sum_{x'}K_x(k_x;x')\sum_{x}M(k_y;x';x)\sum_{y}K_y(k_y;y)I(x,y)$$

The reconstruction process can be divided into three simple steps: IFFT of S along the frequency direction, motion compensation by multiplying the inverse of M for each view, and IFFT along the phase direction. As the first investigation, we implemented this method, called 1D MMFK, and applied it to numerical simulation and volunteer scan.

Numerical simulation & Volunteer scan

In the numerical simulation, the phase direction is along the horizontal axis and the motion is restricted in the vertical direction. Fig.1 (a), (b), and (c) show the upper edge motion of the simulated phantom, the image with normal reconstruction, and the MMFK image, respectively. It is supposed that the maximum displacement is 20% of the FOV and navigator edge detection accuracy is +/-5% of the FOV. On the actual motion and the motion model, it is supposed that as the displacement changes linearly from the bottom of FOV (fixed) to the upper phantom edge (linear expansion model). The motion artifact disappears dramatically in Fig.1 (c).

Fig.2 (a), (b), and (c) show liver images with normal reconstruction, with navigator-based rigid motion correction, and with MMFK, respectively (1.5 T GE HDxt scanner, Whole Body coil, Sagittal, 2D FSPGR, TR/TE/FA/rBW/ST/FOV = 200ms/2.8ms/90/31.3kHz/10mm/32cm, 128x128x1NEX). Compared with Fig.2 (a), the motion artifact is suppressed at region [A] in Fig.2 (b) and (c), because the navigator data are acquired at the diaphragm position. The region [B] is also clearly depicted in Fig.2 (c), where the liver signal is more uniform and a fine line artifact disappears (refer to white arrows in Fig.2 (a) and (b)).

It's our future work to combine MMFK with some method to derive individual-variable non-rigid motion at each data acquisition. Then, the motion model can be optimized for arbitral deformation, which enables higher-quality images.

Conclusion

We proposed a new framework that enables not only non-rigid motion correction with 100% acceptance rate but also rapid reconstruction. As the first investigation, we implemented the 1D non-rigid motion correction, called 1D MMFK, and confirmed the effectiveness with the simple linear expansion model by numerical simulation and volunteer scan.

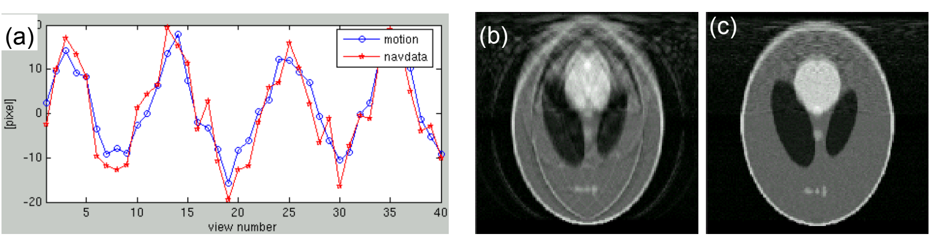

Fig.1

(a) Circle points show actual displacements against phase encode index and star points mean navigator-detected edge motion data.

(b) Image with normal reconstruction.

(c) MMFK image with ideal motion model.

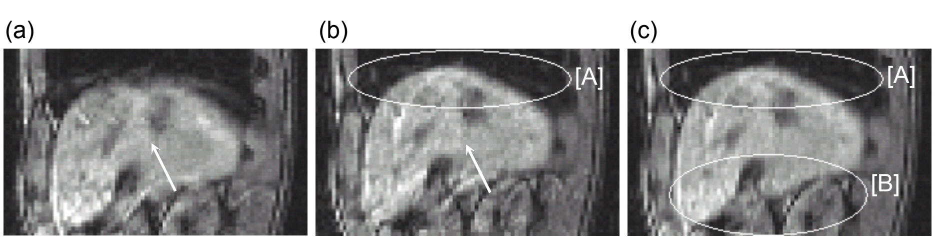

Fig.2

(a) Free-breathing image with normal reconstruction.

(b) Rigid motion correction image based on liver edge navigator data.

(c) MMFK image with linear expansion model.

[1] Freddy Odille et al. Magn reson Med 60:146-157 (2008)