촬상단면내의 MRI 체동 아티팩트의 제거

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Cancellation of MRI Motion Artifact in Image Plane

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Abstract

In this work, a new algorithm for canceling MRI artifact due to translational motion in image plane is described. In the previous approach, the motions in the x direction and the y direction are estimated simultaneously. By analyzing their features, each x and y directional motion is canceled by different algorithms in two steps. First, it is noticed that the x directional motion corresponds to a shift of the x directional spectrum of the MRI signal. Next, the y directional motion is canceled by using a new constraint condition. This algorithm is shown to be effective by using a phantom image with simulated motion.

I. Introduction

Various approaches to correcting the motion artifact have been proposed. Some of them use special pulse sequences for suppressing motion artifact[1,2]. However, since the adjustment of the hardware is difficult, we do not take such approach. Some other approaches only using post-processing are also proposed for this purpose. In most of them, a prior knowledge of motion is required, such as a periodic motion[3~5]. Hedley et al. proposed a artifact cancellation method for 2D translational rigid motions in image plane[6~8]. The features of the method are as follows;

First, no prior knowledge of the motion is required,

Second, the motion may be either periodic or random,

Third, no modification is made to a standard pulse sequence. The region of the image is assumed to be known and to be used as a boundary condition. The phase of data is corrected using an iterative phase retrieval algorithm. Because the algorithm uses a iterative processing, it may take a lot of time, and even has no guarantee for the convergence[9,10].

This method just has the same restrictions of motion and the same features of the method as the Hedley's method. But the problem of convergence is avoided by not using any any iterative procedure. Based on this MRI principle, the property of the influence of the motion in each of x(signal readout) direction, and y(phase encoding) direction is analyzed respectively. In order to correct the artifact due to x directional motion, the x directional Fourier spectrum of MRI signal is analyzed and utilized. It can be regarded as a Fourier weighted projection of the density function onto x axis. Hence, the motion in x direction just corresponds to the shift of spectrum's edge, without regard to the motion in y direction.

The effectiveness of the algorithm is shown by simulations using a phantom with 2D translational motions.

II. MRI Signal and Motion Artifact

MR imaging takes N time intervals. The MRI signal obtained in the n^th^ time interval is expressed as follows:

$$f_n(t)=\frac{1}{N}\sum_x\sum_y \rho(x,y)\, e^{j\gamma(G_x tx + G_y \tau n y)} \tag{1}$$

Where, $\rho(x,y)$ is the density distribution of target, G_x and G_y are the gradients of magnetic field in x and y direction, respectively, and γ and τ are constants. Therefore, MRI signal can be regarded as a 2D inverse Fourier transform of the density distribution $\rho(x,y)$, meanwhile, MR image can be calculated by 2D Fourier transform of MRI signal as shown in Fig. 1(a).

In the procedure of taking a MR image, the interview motion is the main factor of the patient's motion, and the corrupted MRI signal $f'_n(t)$ is given by

$$f'_n(t)=\frac{1}{N}\sum_x\sum_y \rho(x,y)\, e^{j\gamma\, G_x(x+\Delta_x(n))t+\, G_y(y+\Delta_y(n))n\tau} \tag{2}$$

Where, $\Delta_x(n)$ and $\Delta_y(n)$ is the motion in x and y direction, respectively. That is, translational motion causes phase shift in MRI signal. Therefore, some ghost images(artifact) will occur in the reconstructed image by the 2D FFT of the $f'_n(t)$, as shown in Fig. 1(b).

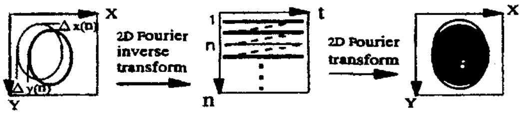

Fig. 1 Mathematical model MRI

III. Cancellation of Artifact due to 2D Translational Motion

When motion does not exist, x directional Fourier spectrum F_{xn} is given by

$$\begin{aligned} F_{xn} &= \Im_t[f_n(t)] \\ &= \frac{1}{\sqrt{N}}\sum_t f_n(t)\, e^{-jk_x tx} \\ &= \frac{1}{\sqrt{N}}\sum_y \rho(x,y)\, e^{jk_y n\tau y} \end{aligned} \tag{3}$$

However, if motion exists, the x directional Fourier spectrum of the corrupted signal $f'_n(t)$ will be given by

$$\begin{aligned} F'_{xn} &= \Im_t[f'_n(t)] \\ &= \frac{1}{\sqrt{N}}\sum_t f'_n(t)\, e^{-jk_x tx} \\ &= \frac{1}{\sqrt{N}}\sum_y \rho(x-\Delta_x(n),\ y)\, e^{jk_y(y+\Delta_y(n))n} \\ &= F(x-\Delta_x(n),\ n)\, e^{jk_y \Delta_y(n)n} \end{aligned} \tag{4}$$

1. X directional Cancellation algorithm

One-short x directional motion causes a shift of F_{xn} in the corresponding line. On the other hand, the x directional Fourier spectrum can be regarded as the projection of the density distribution onto the x axis. When motion does not occur, the edges between zero and non zero of the amplitude of the F_{xn} will take two strait lines along y direction, as shown in fig. 2(a). When target moves $\Delta_x(n)$ at the nth view, the F'_{xn} will shift a $\Delta_x(n)$ in the same direction, which is shown in fig. 2(b). Further, since the motion in y direction only affects the phase of F'_{xn}, but not affecting the amplitude, as shown in Eq. (3). The motion artifact in x direction can be canceled by shifting the Fourier spectrum at the distance of motion, but in the inverse direction.

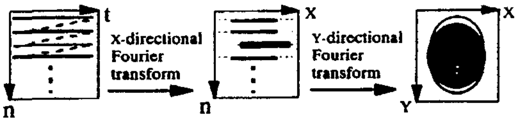

Fig. 2 MRI signal, its Fourier spectrum and the MR image

2. Y directional Cancellation algorithm

After canceling the x directional motion component, the rested motion component is only the y directional motion component. The fourier spectrum F'_{xn} has become into F''_{xn} which is given by

$$F''_{xn} = e^{jk_y\Delta_x(n)n}F_{xn} = e^{jk_y\Delta_x(n)n}\cdot Ae^{j\phi_{xn}} = Ae^{j\phi'_{xn}} \quad (5)$$

where, A and ϕ_{xn} is the amplitude and phase of F_{xn}, respectively, and it is called the phase of image here. ϕ'_{xn} is the phase of F''_{xn}, and it is called the phase of MRI here. The relation between motion component and the true image component is just an algebraic sum as follows:

$$\phi'_{xn} = k_y n\Delta_n + \phi_{xn} \quad (6)$$

On the other hand, the phase of MRI ϕ'_{xn} can be calculated as follows:

$$\phi'_{xn} = \tan^{-1}\frac{Im[F'(x,n)]}{Re[F'(x,n)]} + m_n\pi \quad (7)$$

where, m_n is an integer. Hence, the left side of Eq. (6) is known. The problem is how to separate the motion component and the phase of image ϕ_{xn}.

For this purpose, it is noticed that the F_{xn} is the x directional Fourier inverse transform of density function. According to the feature of density function, a new constraint of the true image component F_{xn} is proposed as follows:

3. Explanation of Constraint

Generally, the y directional density distribution is random, however, the density of a y directional slice line which passes through subcutaneous fat area is nearly symmetric to the origin(Fig. 3(a)). If the density distribution $\rho'(x,y)$ is symmetric about the axis $y = y_c$, according to the Fourier transform shift theorem, the following relation is satisfied.

$$\Im_y[\rho'_x(y)] = e^{jk_y n y_c}\cdot\Im_y[\rho_x(y)] \quad (8)$$

Hence, if the density function along a y directional line is symmetric, then the phase of image ϕ_{xn} on the line is a linear function of n, and i.e.,

$$\phi_{xn} = k_y n y_c \quad (9)$$

This relation is used as a constraint for the phase of image. Substituting Eq. (9) in Eq. (6), the following relation is obtained.

$$\frac{\phi'_{xn}}{n k_y} = y_c + \Delta_n \quad (10)$$

where, y_c is a constant, which affects the reconstructed image as a shift of whole image, but not cause any artifact in the image.

Ⅳ. Simulational Results

The proposed method was evaluated by simulation experiments using a Shepp and Logan phantom shown in Fig. 4(a)[11,12]. The x and y directional motion were given by

$$\Delta_x(n) = 1.8\cos(16\,k_x n) + 1.8\sin(16\,k_x n) \quad (11)$$

$$\Delta_y(n) = 1.8\cos(16\,k_y n) + 1.8\sin(16\,k_y n) \quad (12)$$

$$(\,k_x = k_y = 2\pi/256)$$

The remained motion component was y directional motion. It was canceled by the algorithm mentioned above. Fig. 4(f) shows the density function along a y directional line which passes through the edge of the phantom. Fig. 4(g) shows the phase of the spectrum along the y directional line without y directional motion, and the phase ϕ_{xn} is a linear function of n. Fig. 4(h) shows the phase ϕ'_{xn} when the y directional motion $\Delta_y(n)$ occured. Fig. 4(i) shows the $\phi_x(n)/n\,k_y$, which is regarded as the y directional motion.

Ⅴ. Discussions

Several problems in the above algorithm are discussed here. Regarding the cancellation of x directional motion, only an integer pixel unit motion is canceled, This is also a part of the reason of that some artifacts remain in the final reconstructed MRI. This is shown in the following simulation. The x directional subpixel motion was as follows:

$$\Delta_x(n) = 0.3\cos(16\,k_x n) + 0.3\sin(16\,k_x n) \quad (13)$$

The reconstructed MRI was shown in Fig. 5, in which artifacts are small.

Regarding the cancellation of y directional motion, the phase of MRI ϕ'_{xn} is calculated by Eq. (7). The error of the estimation of ϕ'_{xn} can be corrected by extrapolation. The corrected ϕ'_{xn} is shown in Fig. 5(k), and the reconstructed MRI from the corrected ϕ'_{xn} is shown in Fig. 5(l).

Fig. 6 shows the simulation of which the density distribution along a y directional line through a subcutaneous fat area is not perfectly symmetric and the motions are the same as Eq. (11)~(12). Fig. 6(a) shows the original MRI. Fig. 6(b) shows the MRI before canceling the artifact. Fig. 6(c) shows the asymmetric density distribution along a y directional line. Fig. 6(d) shows the phase of x directional spectrum without motion. Fig. 6(e) shows the estimation of y directional motions ($\phi'_x(n)/n\,k_y$), after canceling x directional motions. Fig. 6(f) shows the reconstructed MRI after canceling the y directional motion component. The result shows the method to be effective in general case.

Ⅵ. Conclusions

Based on principle of MRI, a motion artifact cancellation algorithm has been proposed for 2D translational motion in the image plane. The proposed method is more stable than the conventional iterative phase retrieval method, because no iterative processing is used in this method. The effectiveness of the algorithm was shown by simulation.

On the other hand, this algorithm is only for rigid motions, as this future work, the algorithm for nonrigid motions will be studied. The algorithm was only tested by simulations by now, it will be tested by the real MRI experiment. Further, the algorithm requires a symmetric density distribution along a y directional line. If such a line is not existed, an isotropic object is appended on the target prior to imaging test, the y directional motion will be estimated by a line passing through the object, and the effectiveness will be tested.

References

[12] Eung-Kyeu Kim, "Cancellation of Motion Artifact in MRI", Proceedings of The 26th) KISS Spring Conference '99, pp.582-584. 1999