Object Dependent Phase Encoding Technique

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Introduction

We propose a phase encoding-ordering technique depending on object to be imaged to achieve the reduction of imaging time and progressive image reconstruction. The matching pursuit (MP) is employed to achieve optimal phase encoding-ordering. MP is a recursive algorithm to compute a signal representation with respect to dictionaries of elementary building blocks. The dictionary used in this paper consists of windowed Fourier bases. The windowed Fourier bases give not only spatial resolution but also spatial localization information. By ordering best-matched bases for the phase encoding image reconstruction could be done with fewer bases.

Methods

For dictionary consisting of windowed Fourier bases the object region is divided into several widows spatially in phase encoding direction. With the dictionary, MR signal can be decomposed as

$$S_p(m,n) = \iint \rho(x,y) W(\frac{x-x_p}{B}) e^{-ik_x x} e^{-ik_y y} dxdy, \qquad (1)$$

where $W(\frac{x-x_p}{B})$ is window function, $k_x = \gamma G_x Tm$, $0 \le m \le M-1$ and M is a number of pixel in window. To order bases in windowed Fourier dictionary before 2-dimensional imaging, MP algorithm is applied for 1-dimensional projection signal of the image. With the initial condition of $R^0 p(x) = p(x)$, a windowed Fourier basis is chosen in the dictionary so that it best matches the residual signal of $R^k p(x)$ as

$$\left|\langle R^k p(x), \omega_{\gamma_k}(x)\rangle\right| \ge \sup_{\gamma\in\Omega}\left|\langle R^k p(x), \omega_{\gamma}(x)\rangle\right|, \qquad (2)$$

where $\omega_{\gamma_k}(x)$ is chosen as best matched basis at k-th iteration and belongs to the dictionary of Ω and $\langle\rangle$ is inner product. Finding windowed Fourier bases in the dictionary is repeated from $k = 0$ to N-1 so that N windowed Fourier bases in the dictionary are ordered according to the criterion of equation (2).

To apply the ordered windowed Fourier bases to the object, 90-degree RF pulses are excited with x-directional gradient. The RF pulses are generated so that their response to the object leads to producing windowed Fourier bases onto the object. Generally RF pulses are designed by inverse Fourier transform of windowed Fourier bases in case that linear gradient applied. By superimposing windowed Fourier bases onto the object, the MR signal integrated over the object can be written as

$$S_F(m,n) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \rho(x,y)\omega_{\gamma_m}(x) e^{-iG_y \delta n y} dy. \qquad (3)$$

Note that $\omega_{\gamma_m}(x)$ is ordered windowed Fourier basis using MP algorithm and the MR signal is sampled with y-directional reading gradient. Since windowed Fourier bases chosen optimally so that they have best matched the object function, only some MR signals encoded by optimal windowed Fourier bases in the dictionary are sufficient to reconstruct $\rho(x,y)$.

After acquiring the MR signal at each encoding step, which can be represented as equation (3), a 1-dimensional Fourier transform in the reading direction (y-direction) is performed so that one can obtain $< \rho(x,y), \omega_{\gamma_k}(x) >_x$. The reconstruction is performed as

$$\rho_{k+1}(x,y) = \rho_k(x,y) + < \rho(x,y), \omega_{\gamma_k}(x) >_x \omega_{\gamma_k}(x), \qquad (4)$$

where $\rho_{k+1}(x,y)$ is newly updated image and $\rho_0(x,y) = 0$.

Since basis function is repetitively selected so that it matches best with the residual signal the resolution of the reconstructed image is progressively improved with increasing ordered phase encoding. Therefore one can achieve a progressive reconstruction at each encoding step, *i.e.*, a low-resolution image can be obtained with a few iterations and the resolution of the image can be improved with additional encoding steps. Further, one can stop the iterations if the image quality is satisfactory, which leads to a possibly reduced imaging time. In the following section, we will demonstrate the matching pursuit algorithm in MR imaging and its usefulness to adapt the object by computer simulations.

Experimental Results

To verify the usefulness of proposed object dependent phase encoding algorithm, specifically for reduction of imaging time, computer simulations and experiments were performed. For windowed Fourier bases, object is segmented into 8 windows. As simulation results, reconstructed images with fewer bases are shown in figure 1 (a). As is seen, edge parts of image are degraded by truncation artifact or ringing artifacts due to fewer bases. Based on the criterion in equation (2), waveforms in windowed Fourier dictionary were ordered. Then the phantom image was decomposed according to the ordered waveforms. As shown in the figure 1 (b), even with fewer bases, image is reconstructed sufficiently so that truncation artifact is eliminated.

In experiments, a phantom imaging was performed with 1.0 T whole body MR scanner. Figure 2 (a) shows images reconstructed using conventional Fourier transform. As is seen truncation artifacts are generated around edges due to insufficient number of bases. However the truncation artifacts are reduced when the object dependent phase encoding method is used as shown in figure 2 (b). 4 windows were used in windowed Fourier transform and matrix size was 256x256. This shows that the optimal phase encoding-ordering algorithm provides optimal choice of waveforms which match the object to be imaged. Therefore the proposed object dependent phase encoding algorithm leads to reduction of imaging time.

Conclusions

As a conclusion, the matching pursuit algorithm is applied to MR imaging with a windowed Fourier dictionary. It is found that the proposed technique gives a local spatial information and the reduction of imaging time.

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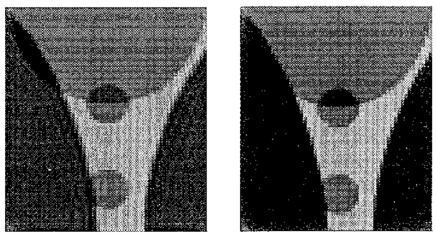
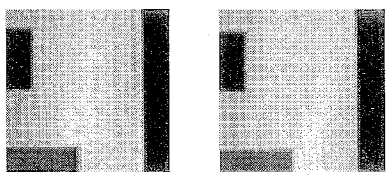


(a) (b)

Figure 1. (a) Image for conventional MRI. As is seen, truncation artifacts are shown due to insufficient bases. (b) Image by ordering optimal phase-encoding. Note that 194 phase encodings are used for image reconstruction.



(a) (b)

Figure 2. Experimentally obtained images reconstructed by (a) conventional Fourier transform technique and (b) proposed phase encoding-ordering technique.