Image Reconstruction with a PERiodic and Linear (PERL) Spatial Encoding Field

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Introduction

In prior work [1-10], we proposed the use of the PERL field given by $B_p(x,y) = G_p y \sin(qx+\theta)$ where $\lambda = 2\pi/q$ is the spatial wavelength. Using this field as a pre-encoding pulse, of duration *T*, provides several advantages; rapid acquisition, lower signal dynamic range, spatial localization, no aliasing, and some degree of motion insensitivity. The NMR signal acquired with this pre-encoding pulse in the presence of a standard readout gradient, Gx, is given by:

$$S_n(t) = \iint \rho(x,y)\exp(i\gamma(G_p T y \sin(qx+\phi+\theta_n) - G_x t x))\,dx dy \quad \textbf{(1).}$$

Eq.(1) may now be decomposed into a sum of signals [1-3] as given by:

$$S_n(t) = \sum_k S_{nk}(t-t_k)\exp(ik(\phi+\theta_n)) \quad \textbf{(2)}$$

where $S_{nk}(t-t_k) = \int \rho_k(x)\exp(i(kq-\gamma G_x t)x)\,dx$ **(3)** with $t_k = kq/\gamma G_x$ **(4)** and $\rho_k(x) = \int \rho(x,y) J_k(k_y y)\,dy$ **(5)**

where $k_y = \gamma G_p T$. From Eq. (3), $S_{nk}(t-t_k)$ may be interpreted as an echo whose center is at t_k, Eq. (4). Thus the PERL sequence spontaneously generates echoes. If the spatial resolution, $xres < \lambda$, then the echoes overlap significantly such that there are $N = \lambda / xres$ overlapping echoes which may be unwrapped through the collection of *N* $S_n(t)$ signals with each signal having a different spatial phase encode (SPE) offset, θ_n. The Bessel transform is solved with the introduction of a new set of basis functions, $M_k(k_y y)$, that are orthogonal to the Bessel functions [8,9,10]. These functions also satisfy the important relation: $\sin(k(x-y))/(k(x-y)) = \pi/2 \sum_{n=-\infty}^{\infty} J_n(kx) M_n(ky)$ **(6)**, demonstrating that the reconstruction has a sinc point spread function along both directions even though only one dimension is Fourier transformed.

Methods

Fig. 1 shows the overall flow diagram for the PERL image reconstruction. The generation of the *M* functions (as a table of values) needs to occur only once for a given number of indices, *kmax*, and k_y value and hence it is at the top of the flow chart. The *M* table is quickly calculated using its Fourier form [8] and FFT. After *N* SPE $S_n(t)$ signals are collected, the signals must be phase corrected for a B_o component which is generated by the PERL field coil. The phase is calculated at the center of the signal corresponding to the *k=0* echo in Eq.(2). An FFT along the SPE direction increases the echo separation spacing to *R* points. From Eq.(2), a first order phase correction with respect to *k* is required to account for the spatial phase offset, ϕ. An FFT of each echo performs the reconstruction along *x.* A final matrix multiplication, $\rho(x,y) = \sum_k \rho_k(x) M_k(k_y y)$, reconstructs the final image. These procedures have been implemented in Mathematica as well as in Matlab software packages.

An alternative procedure is essentially based upon an FFT of the $S_n(t)$ without unwrapping the echoes. This allows the use of the entire time domain with the advantage of eliminating artifacts that may arise from echo overlap.

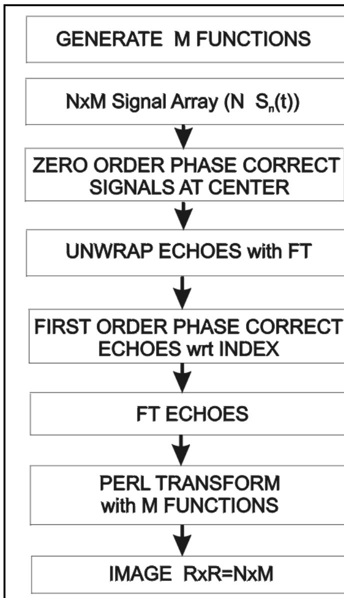

Figure 1.
RECON FLOW CHART

Discussion and Conclusion

The reconstruction is fast (taking about a second in Matlab). The major difficulty in the reconstruction lies with the determination of the B_o component artifact and ϕ. Both of these values are related to the position of the PERL coil and would be constant for a fixed position.

The PERL signal may be viewed as a method that encodes both *X* and *Y* information along time. Thus, the signal array is rectangular as opposed to the typical square-like MRI *k*-space data set. The original reconstruction matches this approach in that it separates the *X* and *Y* information in the time domain. The alternative reconstruction provides a viewpoint whereby *Y* information is encoded into adjacent *"X"*-like pixels. Separation of the *Y* information then occurs in one of the image domains.

References

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