Book of Abstracts

Volume 2

SMRM

Society of Magnetic Resonance in Medicine

Tenth Annual Scientific Meeting and Exhibition
August 10-16, 1991
San Francisco, California, USA

ISSN 0891-7612

Simultaneous proton density and T_2 weighted image reconstruction

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Introduction

The M.R.I. signal, in the presence of a linear gradient, due to T_2 is the inverse Laplace and not the inverse Fourier Tranform (FT) of the projection. Thus, computing the Laplace Tranform of the signal one can extract both the spatial and the T_2 information. Therefore one can obtain proton density and T_2 weighted images using a unique set of acquired data, that is from a single pulse sequence.

The Laplace Tranform of a discrete sequence is the Z Tranform (ZT). Implementation of the ZT instead of the DFT (Discrete Fourier Transform) is expected to improve the resolution of the frequency encoded images.

Analysis

The ZT X(z) of a finite length sequence x(n) non-zero for $n_1 \le n \le n_2$ is defined as the FT of the sequence $\{r^{-n}x(n)\}$ for all values of r that the FT exists, that is

$$X(z) = \sum_{n=n1}^{n2} x(n)z^{-n}, \quad z=re^{j\omega} \qquad (1)$$

It is straightforward to show that

$$ZT\{x(n)\}\Big|_{|z|=a} = FT\{a^{-n}x(n)\} \qquad (2)$$

This result shows that the DFT provides the means for the computation of samples of the ZT of a finite length sequence taken at equally spaced points around a given circle (1). The ZT is a generalisation of the DFT in the same manner as the LT is a generalization of the FT.

The MRI signal is a sum of exponentially damped sinusoids, each at a different rate of decay, imposed by the T_2 value of the corresponding voxel. Every term of this sum is characterised by its frequency and its T_2 value, and is represented by a pole on the complex z-plane (1). Identification of such a pole can be achieved by implementing the ZT.

Evaluating the DFT is equivalent to computing the ZT for r=1 (eq.(2)), where r=|z| (eq.(1)). As the ZT is computed for different values of r sharper resonance peaks appear when a pole is approached (fig. 1). The physical meaning of this result is that as one evaluates the ZT closer to a pole the corresponding damped sinusoid is becoming an ideal undamped sinusoid which is represented by a "delta" function in the frequency domain. Thus, T_2 identification can be achieved by finding the locations where sharp resonance exist.

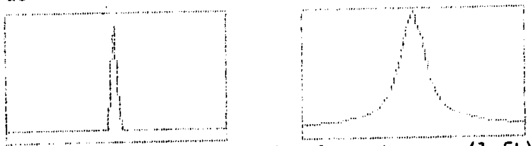

Figure 1:ZT of a spin isochromat near (left)and far (right) from the corresponding pole.

Discussion

Obviously, the more sharp resonance is obtained the less imaginary part amplitude (dispersion mode) the FFT of the FID has. Thus, one criterion for the estimation of T_2 is the absence of significant imaginary part in the specific frequency. Alternatively one can test the phase of the FFT, which as well lessens when the path in the z-plane approaches a pole.

In figure 2 is shown the behavior of the imaginary part of a particular frequency as a function of the radius r in the z-plane, that is as a function of the T_2 value. It is evident that from successive samples in the z-plane one can easily work out where the desired minimization of the imaginary part of the FFT appears.

Because the proposed method depends on the situation of zero phase, any phase error present must be corrected as proposed, for example, by Lai and Lauterbur (2).

Conclusion

Proton density and T_2 weighted images should no longer be considered as two completely independant imaging techniques. A single pulse sequence is sufficient to extract both images if ZT is implemented.

The proposed method not only offers the opportunity to obtain both the spatial and the T_2 proton distribution of the imaged volume, but also to remove the broadening effect of T_2 on the reconstructed image resulting to higher image resolution.

The required additional post processing becomes insignificant today, given the rapid evolution of computers.

References

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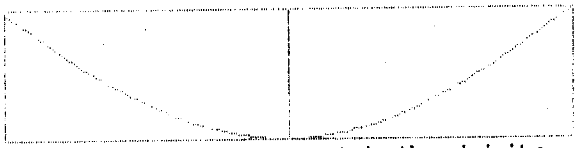

Figure 2: The imaginery part in the vicinity of a pole.