Iterative Signal Decay Correction: Application to 2D Ultra-short TE Imaging

D. Mentrup[1], H. Eggers[1]

[1]Sector Technical Systems, Philips Research, Hamburg, Germany

Abstract

Ultra-short echo time (UTE) imaging has been developed to visualize tissue components with T_2 relaxation times in the order of 0.1 ms (1,2). While TE can be brought down below such values, readout durations may extend over a few milliseconds due to physiological and technical limits of the gradient amplitude and rise time. Consequently, significant decay of the transverse magnetization occurs during the readout, giving rise to a loss of signal intensity and spatial resolution for structures with short T_2. This work presents an iterative reconstruction algorithm for the correction of these adverse effects, which relies on a reference scan to determine the spatial distribution of T_2. It reports on the application of this algorithm to simulated and experimental data and shows that image quality can be enhanced substantially.

Methods

The acquired *k*-space data $\underline{m}$ is modelled by

$$\underline{m} = E\,\underline{x}\,,$$

where $\underline{x}$ denotes the image vector to be reconstructed. The elements of the encoding matrix *E*,

$$E_{\kappa\rho} = e^{i r_\rho k_\kappa} e^{i\Delta\omega(r_\rho)t(k_\kappa)} e^{-t(k_\kappa)/T_2(r_\rho)}\,,$$

are composed of three exponentials describing the Fourier encoding by the gradient system, the influence of the field inhomogeneity (angular off-resonance frequency $\Delta\omega$) and of the transverse relaxation (time constant T_2), respectively. The iterative reconstruction algorithm employed in this work solves the linear system of equations

$$E^H E\,\underline{x} = E^H\,\underline{m}$$

using the conjugate gradient method (3) and a segmentation of time in combination with the interpolation strategy proposed in Ref. 4.

Its effect on image quality was first studied in simulations. *k*-space data sets were synthesized for a visibility phantom consisting of five columns of circles of decreasing size (Fig. 1a). Each column was assigned a different decay rate, such that imaging was effectively performed for different values of the ratio T_2/T_{AQ}.

UTE imaging experiments were then carried out on a 3.0 T whole-body MR system (Gyroscan INTERA, Philips Medical Systems, Best, The Netherlands) using half-sinc RF excitation pulses and radial FID sampling (1). Dedicated resolution phantoms containing nine rows of five rectangular, milled holes with bore diameters ranging from 2.0 mm down to 0.5 mm were filled with aqueous solutions of iron chloride ($FeCl_3$) to shorten the relaxation time (T_2=1.1, 0.8, 300, 0.6 ms from top left to bottom right in Fig. 2). Firstly, a field map was acquired, which then was used in the reconstruction of a sequence of ten images measured with TE=0.1,…,1 ms. This sequence served for the determination of the decay map by exponential fitting. Secondly, both the field and the decay map were applied to a different data set acquired with low readout bandwidth (T_{AQ} =1.33 s).

Results and Discussion

Fig. 1 displays simulation results for a selected data set, reconstructed both without and with signal decay correction (columns from left to right: T_2/T_{AQ} = infinity, 0.53, 0.27, 0.18, 0.13). In Fig. 1b, due to the decrease of T_2 from left to right, the signal intensity of the circles drops, and the blurring increases. Note that the loss of signal intensity becomes more pronounced from top to bottom, i.e., with decreasing size of the circles. This may be attributed to the blurring, since an individual pixel in a small structure does not receive signal from neighboring pixels.

In the image obtained with the iterative correction (Fig. 1c), the signal intensity of the decaying circles is almost perfectly restored, and their visibility is thereby improved. Moreover, the blurring of the circles is largely removed.

Fig. 2 shows reconstruction results for the measured data set. From a comparison of Fig. 2a and 2b, it is evident that large off-resonance effects occur due to the high concentration of the paramagnetic ions. They demand a careful correction. In Fig. 2c, the benefit of the signal decay correction is most significant in the lower right phantom containing the highest concentration of iron chloride. The visibility and sharpness of the top two rows of milled holes improves considerably.

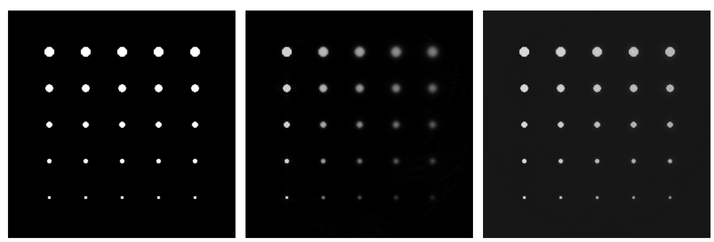

Fig. 1. (a) The visibility phantom, (b) reconstruction without correction, (c) reconstruction with correction after 20 iterations.

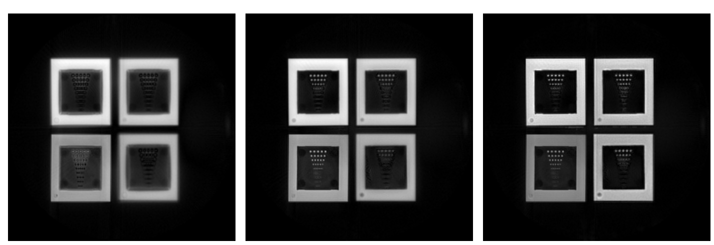

Fig. 2. Reconstructions of the measured data set, (a) without correction, (b) with off-resonance correction only, (c) with both off-resonance and signal decay correction.

Conclusion

The specific imaging scenario encountered in UTE imaging, including short T_2 species and readout times significantly longer than T_2, entails substantial signal decay during data sampling causing adverse effects on image quality. The present work gives a proof of basic feasibility to correct for these effects with an iterative reconstruction algorithm, which is based on a separate estimation of the local signal decay. This correction is particularly useful to enhance the visibility of small, rapidly decaying structures and to restore spatial resolution in areas of short T_2. It is also of potential benefit for standard T_2 values in sequences that require long readout trains, like echo-planar and spiral imaging, where the correction may facilitate the use of prolonged acquisition windows.

References

1. Pauly J, et al., Proc SMRM 1989; 28.
2. Robson MD, et al., J Comput Assist Tomogr 2003; 27:1-22.
3. Pruessmann KP, et al., Magn Reson Med 2001; 46:638-651.
4. Sutton BP, et al., IEEE Trans Med Imag 2003; 22:178-188.