The DICOM Standard: Is Twelve Bits Enough?

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Introduction

MR scanner vendors have interpreted the international DICOM standard for medical image storage as dictating that, for pixel data, 12 bits are allocated for image intensity and 4 bits for masking or overlays(1). Accordingly, the image intensity is scaled to 12 bits (0-4095). As most MR scanners digitize data with at least 16 bits of resolution, this scaling can lead to a loss of information. This study explores effects on two common quantitative MR modalities, functional MRI (fMRI) and diffusion tensor imaging (DTI), which can employ a dynamic range of signal intensity that exceeds the 12 bit limit.

Methods

The human eye is not sensitive to 4096 gray levels of dynamic range, so the 12 bit DICOM standard will not affect the appearance of static images. Quantitative imaging, however, relies on post-processing methods to calculate physical parameters, as with DTI, or statistical measures, as with fMRI. In many cases, this post-processing is performed on data after it is converted to DICOM format. In this study, we performed simulations of fMRI and DTI experiments in order to understand the impact of the data truncation imposed by the 12 bit limitation. Human data were acquired to verify the simulations.

<u>Simulations</u>

The issues with regard to pixel dynamic range differ between fMRI and DTI. We describe the simulations separately.

<u>fMRI</u>: For fMRI, long time series are acquired with a BOLD weighted acquisition and the data are analyzed for a statistically significant change in MR signal coincident in time with the execution of a specific task. It is important to assess a mean shift in time from temporal fluctuations caused by system and physiologic fluctuations. Simulations were run with different signal-to-noise ratios to determine the impact of image bit-scaling on the sensitivity of a typical fMRI paradigm acquisition. *Simulated fMRI paradigm*: 160 repetitions, sampling rate=2 seconds, 0.5% signal injected in block style with 32 second on/32 second off timing. *Signal-to-noise ratio*: The temporal signal-to-noise ratio was simulated for SNR=100, 500, 1000, 3000. *Scaling*: The effect of image scaling was estimated for mean tissue signal intensities of 512 (9 bits) and 4096 (12 bits). The reason for testing the two scaling levels is that, in order to assure that there are no signal overflows in the bit conversion process, the mean value of signal intensity of gray matter in a BOLD-weighted acquisition is adjusted to approximately 500 (referred to hereafter as scanner auto-scaling). This assures that CSF, which has much higher signal, will still be within the 12 bit range. The 4096 scaling was used to illustrate the best-case scenario within the context of the 12 bit standard.

<u>DTI</u>: In DTI, diffusion of water in a given direction is assessed by applying a diffusion gradient in that direction and comparing the signal obtained to that with no diffusion gradient. It is necessary that the images acquired with diffusion gradients on and off have the same scale. The diffusion gradient suppresses the MR signal with exponential sensitivity to the diffusivity, so the range of diffusivity that can be measured will be critically affected by the necessity to measure both b=0 data and $b \neq 0$ images with 12 bit dynamic range in signal intensity. We simulated a DTI acquisition of a single voxel with ellipsoidal diffusion profile with several b values and gradient schemes to examine the impact of the 12 bit scaling on potential DTI experiments. b values of 1000, 2000, 4000, and 10000 s/mm^2 and gradient trajectory sets with 6, 66, 128, and 512 directions were studied.

<u>Human Studies</u>

Custom pulse sequences were employed that record image data at full, 24 bit, and standard, 12 bit resolution. Data were acquired in three subjects on a 3T Trio MRI scanner (Siemens Medical, Erlangen) according to the following fMRI and DTI protocols.

fMRI Activation study: 160 volumes of 31 4mm thick axial slices were acquired using a prospective, motion-controlled, EPI acquisition. TE/TR/flip=29ms/2000ms/80^o, 64x64 matrix, 256mm x 256mm FOV, receive bandwidth=125 KHz. The subject executed a block-style fMRI motor paradigm consisting of interleaved blocks of 32 seconds rest and 32 seconds complex finger tapping.

DTI: 31 2mm thick axial slices were acquired with 66 diffusion gradient directions (b=2000 mm^{-2} s) and fourteen b=0 acquisitions per slice with a twice refocused EPI sequence(2). TE/TR=101ms/4800ms, 128x128 matrix, 256mm x 256mm FOV, 5/8 partial Fourier, receive bandwidth=125 kHz.

<u>Data Analysis:</u> fMRI data were analyzed for simulation and human studies by least-squares fitting the time series for each pixel to a boxcar reference function plus a slope(3). Student's t vs. percent activation was plotted for motor regions. The slope of the resulting plot indicates the sensitivity of the scanner. The human data were used to assess the impact on sensitivity in a realistic situation with current technology. DTI data were analyzed by determining, for each voxel and diffusion gradient direction, the percent difference between signal intensity measured at 24 and at 12 bit resolution. The maximum difference among diffusion gradient directions is shown, as it reflects the effect of low bit resolution for the gradient directions that cause maximal diffusion weighting.

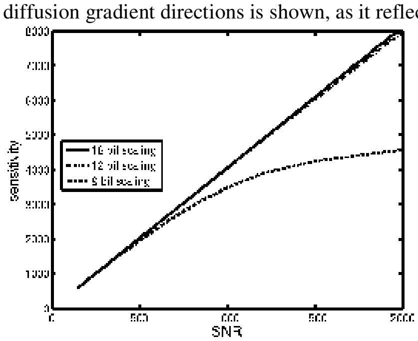

Figure 1

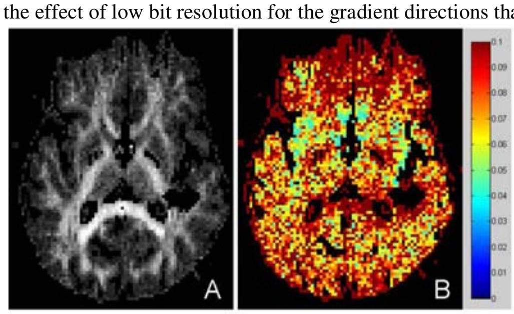

Figure 2

Results and Discussion

Figure 1 shows the sensitivity for BOLD detection as a function of temporal SNR for the 3 scaling scenarios. Significant loss of sensitivity is noticed in the 9-bit scaling (scanner auto-scale) case for SNR~500, as determined from simulations. Human data demonstrated the loss of sensitivity when using spatial filtering methods that enhanced the temporal SNR to 500. DTI simulations indicated that a significant impact on measured diffusion properties would be evident for scanner autoscaling for b values at or above b=2000 mm^{-2} s. Figure 2B shows the fractional difference in diffusion profile measured by auto-scaling and original 24 bit resolution. Marked differences (>10%) are seen in regions with high fractional anisotropy (figure 2A) such as the splenium.

Conclusion

This study demonstrates that there are experimental conditions under which the 12-bit pixel storage standard used by MRI vendors adhering to the DICOM standard can significantly affect experiment results. In particular, for DTI experiments, care should be taken when b-values at or above 2000 mm^{-2} s are used. For fMRI experiments, researchers using custom gradient and RF coils where temporal SNR approaches the mean signal of the tissue being studied should be careful to avoid the standard scaling. MRI vendors and researchers are encouraged to recognize that this issue will become more limiting as technical advances improve the sensitivity of dynamic imaging methods.

References

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