Fast EPR Acquisition with Adaptive Heterogeneous Clocking (AHC)

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Abstract
Electron Paramagnetic Resonance Imaging (EPRI) can provide insight into in vivo anatomic and functional imaging of free radicals and paramagnetic molecules and their role in disease in small animal models. However, there is a need to expedite the data acquisition and post-processing to enable new EPRI applications. While previous work has used a fixed-rate master clock to pace all A/D and D/A conversion activities of the data acquisition electronics, Adaptive Heterogeneous Clocking (AHC) significantly reduces communication between the host computer and gradient hardware by using different clocks to pace the A/D and D/A functions of our acquisition cards. Projections containing up to 4096 points can be acquired in as little as 10 – 20 ms using AHC. Nearly real-time acquisition can be performed for complex computer-generated gradient waveforms, which will enable a variety of new sampling patterns.

Introduction
Integrated EPR/NMR MRI technology and instrumentation has the potential to uniquely enable both in vivo organ specific mapping of free radicals, oxygen and nitric oxide in small animals such as mice along with NMR based functional and anatomic imaging [1, 2]. This technology is very promising but several fundamental problems presently limit its development and biomedical application. These include the need to expedite the data acquisition and post-processing. While the spinning gradient [3] and rapid scan methods [4] improve the acquisition speed, there is still further potential to improve the acquisition speed by designing novel clocking schemes. Previous work has used a fixed-rate master clock to pace all A/D, D/A conversion activities of the data acquisition electronics, including gradient and field sweep waveform generation, and projection data acquisition. The drawbacks of this scheme include: redundancy in generated gradient and field sweep waveform data and significant PCI bus bandwidth limitations. Redundant projection data also significantly increases post-processing time and the total time of subsequent acquisitions. Therefore we propose a new acquisition clocking scheme to enable novel and exciting acquisition strategies.

Methods
The proposed acquisition scheme is Adaptive Heterogeneous Clocking (AHC), which utilizes a fast clock to pace the A/D conversion for projection data acquisition in order to achieve a high sampling rate, and a slow clock to pace the D/A conversion for gradient and field sweep waveform generation. The clock rates are automatically adjusted according to the magnetic field sweep time. For long sweep times, the sampling rate is low to reduce the redundant data; but for short sweep times, the sampling rate is high to guarantee sufficient data. AHC significantly reduces the communication bandwidth and increases the acquisition speed. Our preliminary work with nitroxide phantoms (TEMPONE, TEMPOL) indicate that the fidelity of gradient and sweep waveforms is degraded if the ratio of the A/D and D/A clocks is reduced excessively. We empirically determined a relationship between the acceptable clock ratios according to Eq. (1), which relates magnetic field sweep time (*TM*, seconds), the A/D clock rate ($Clock_{AD}$, Hz), and D/A clock rate ($Clock_{DA}$, Hz) for sampling 4096 data points.

$$Clock_{AD} / Clock_{DA} = 10 - 30 \log TM \qquad \text{for } 0 < TM \le 1\,\text{sec} \qquad \text{Eq. (1)}$$

Results
Spectra acquired using AHC showed no signs of distortion or baseline drift for a clock ratio of 64 and a very short sweep time (Fig. 1). Reconstructed 2D images from AHC data were also undistorted and had high SNR (Fig. 2). Compared to the fixed homogeneous clocking acquisition scheme, AHC reduces the dead time in acquisition by up to 80%, and reduces the post-processing time by more than 96% for long sweep times (Fig. 3). Furthermore, AHC can also achieve very short sweep time of 10 – 20 ms, which is not achievable with fixed homogeneous clocking due to insufficient sampling rate.

Discussion
Potential applications of this work include measurement and imaging of myocardial oxygenation, redox state, nitric oxide formation. Previous experiments have been limited by long minimum projection acquisition time and long dead time. This acquisition time reduction removes the speed limitation and enables us to achieve gated imaging for more applications. While others have developed high performance hardware-based gradient waveform generation using function generators [5, 6], AHC is based entirely on software-generated waveforms, allowing much more flexibility in designing novel acquisition schemes.

References and Acknowledgements. [1] Ahmad et al. J Magn Resonance 2010; 207(1):69-77. [2] He et al. MRM 2002; 47(3):571-8. [3] Deng et al. J Magn Resonance 2007; 185(2):283-290. [4] Stoner et al. J Magn Resonance 2004; 170(1):127-135. [5] Sato-Akaba et al. Analytical Chemistry 2009; 81(17):7501-6. [6] Joshi et al. J Magn Resonance 2005; 175(1):44-51. This work was supported by NIH 5R01EB004900 (Proton Electron Double Resonance Imaging (PEDRI) of Free Radicals) and conducted at The Ohio State University Medical Center.

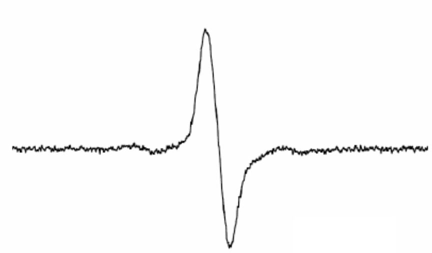

Fig. 1. Acquired spectrum with field sweep time of 20 ms

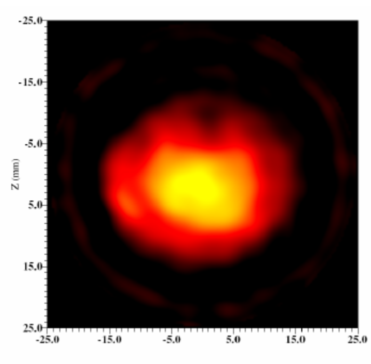

Fig. 2. Acquired image of a phantom with *TM* = 20 ms

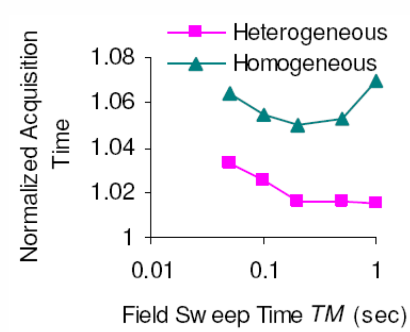

Fig. 3. Comparison of actual acquisition times