One step real-time image correction with GUSTO (Gradient warp and UnderSampled Transform Operator)

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Introduction: Fast imaging applications require high frame rates and low latency, thus the choice of image acquisition parameters and image reconstruction algorithms is crucial. For example, reducing the number of phase-encodings reduces overall scan time, but reduces spatial resolution. Furthermore, algorithms for gradient warp correction are cumbersome for real-time image reconstruction.[1] We propose a new strategy that utilizes a calibration scan[2] to produce gradient warp corrected images from vastly undersampled data. Unlike parallel imaging, this technique uses only a single coil. Our hypothesis is that the **G**radient warp and **U**nder**S**ampled **T**ransform **O**perator (GUSTO) algorithm can produce images in real time with an increased frame rate while preserving good geometric fidelity.

Theory: Treating images as vectors allows use of general linear algebra; a $N_x \times N_y \times N_z$ image volume is treated as a $1 \times (N_x * N_y * N_z)$ vector. A product-sequence gradient wrap corrected, fully sampled volume is obtained from a calibration scan, and vectorized to form a calibration image, $\mathbf{I_{CAL}}$. Then undersampled data was obtained during real-time acquisitions, reconstructed into uncorrected, aliased image data, and then vectorized, $\mathbf{I_{GUS}}$. Each value in the aliased uncorrected image, $\mathbf{I_{GUS}}$, maps to $\mathbf{I_{CAL}}$ by way of a transform matrix $\mathbf{T_{GUSTO}}$. This relationship can be expressed mathematically as $\mathbf{I_{CORR}} = \mathbf{T_{GUSTO}}\ \mathbf{I_{GUS}}$, where $\mathbf{I_{CORR}}$ is the corrected image. Matrix $\mathbf{T_{GUSTO}}$ was determined using spatially weighted representations of the correct image, $\mathbf{I_{CAL}}$, vectorized to be the rows of the operator matrix. With $\mathbf{T_{GUSTO}}$ subsequently acquired raw data acquired in the same orientation can be corrected by multiplication with $\mathbf{T_{GUSTO}}$.

Methods: Using a clinical 3 T MR scanner (GE Signa VH/*i*, GE Healthcare, Waukesha, WI), a 30 cm FOV, 64 × 64 fully sampled and gradient warp corrected image ($\mathbf{I_{CAL}}$) was collected using a single-channel body coil and TR = 2.3 ms (Fig 1a). Raw Fourier data was then sampled and used to reconstruct $\mathbf{I_{GUS}}$. Raw data was acquired via TCP/IP with a computer client (Mac Mini, Mac OS 10.5, 2 GHz Core 2 Duo, 4 GB of RAM). MATLAB (the MathWorks inc., Natick, MA) algorithms were developed to create the matrix $\mathbf{T_{GUSTO}}$ using $\mathbf{I_{CAL}}$, and then to create the corrected images, $\mathbf{I_{CORR}}$, from the uncorrected data, $\mathbf{I_{GUS}}$. Spatial dependence was introduced to $\mathbf{I_{CORR}}$ with a 2D window function that was focused about the aliasing points. Undersampling was simulated by removing every n^th^ raw Fourier data *k*-space line. Undersampling factors of $n = 1$, 2, and 16 were used.

Results: Figs 1e-g show the images produced by applying the GUSTO algorithm to the undersampled uncorrected data sets. The fully sampled image (Fig 1a) was acquired in 147 ms. Images could be acquired in 9.2 ms using a calibration scan (Fig 1g).

Discussion and Conclusion: The results shown in Fig 1e-g demonstrate a proof-of-concept for the GUSTO algorithm performing direct gradient warp correction of undersampled data. One difficulty with this technique is the demands it puts on computer hardware such as the memory, particularly, when increasing the acquired resolution. This problem can be overcome by increasing the amount of RAM and streamlining the vector calculation methodolgy, potentially, by using an array processor. In the future, we intend to investigate this algorithm for real-time passive catheter tracking applications by assessing its performance with motion.

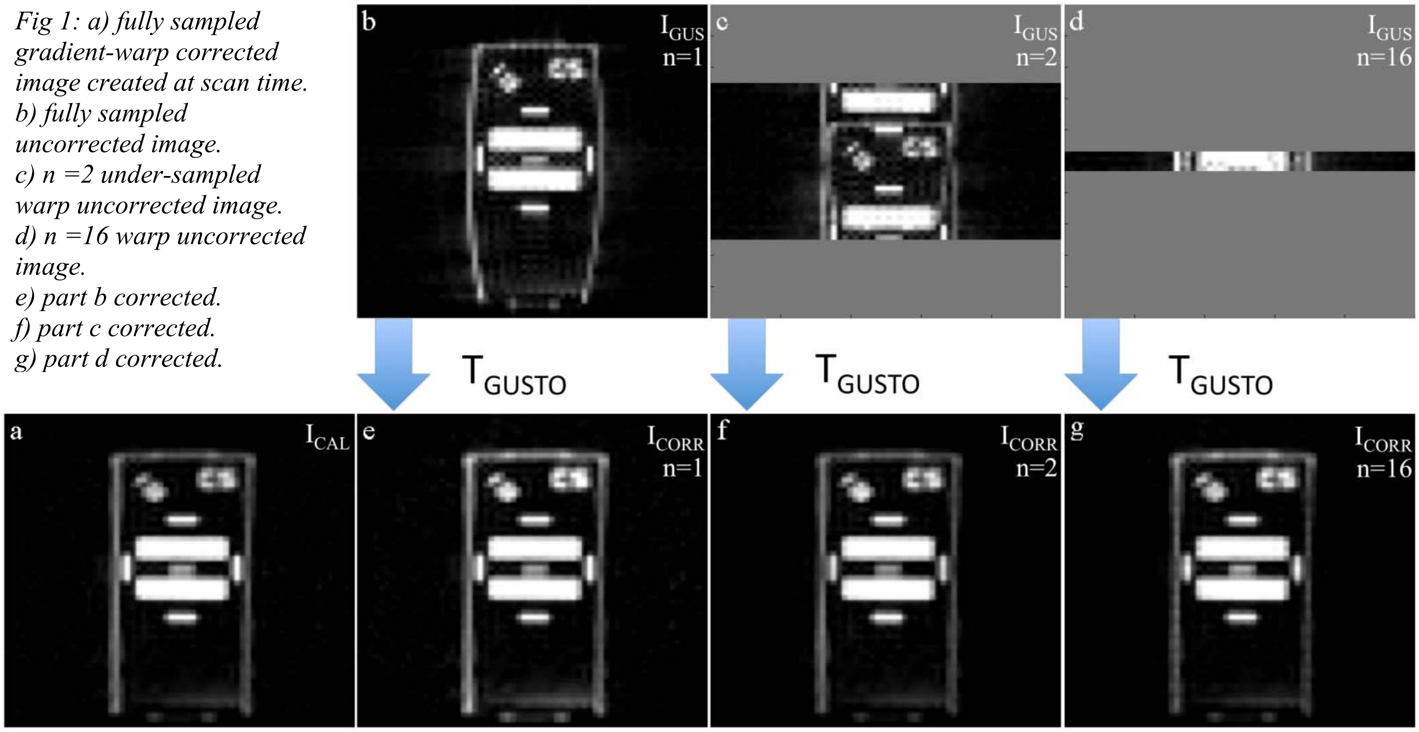

Fig 1: a) fully sampled gradient-warp corrected image created at scan time.
b) fully sampled uncorrected image.
c) n =2 under-sampled warp uncorrected image.
d) n =16 warp uncorrected image.
e) part b corrected.
f) part c corrected.
g) part d corrected.

References: [1] Janke A, *et al.*, *JMRM,* 2004; 115 [2] Pruessmann KP, *et al.*, *JMRM,* 1999; 952