Correction of 3D Truncation Artifacts in Knee and Breast Imaging

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Introduction: Three-dimensional magnetic resonance imaging often requires long acquisition times. Scan durations are commonly shortened to accommodate breath-hold sequences, data acquisition during a contrast bolus, and limited scanner availability. Consequently, a minimum amount of data is collected to reduce scan time. In decreasing the amount of data collected, artifacts may result manifesting in Gibbs ringing in the direction of truncation. This study focuses on results from truncation in the slice encode (kz) direction. Rather than zero filling truncated k-space, a modified linear prediction (LP) algorithm proposed by Martin et. al. [1] can be used to interpolate uncollected lines. Although originally intended for 2D imaging, the algorithm can be applied in a third dimension to diminish truncation artifacts in the z direction. Potential 3D truncation artifacts include wrapping between the beginning and ending slices, residual Gibbs ringing from the in-plane direction, and apparent ghosting artifacts from adjacent image ringing. Clinical applications that can benefit from this artifact reduction include knee cartilage imaging and breast imaging with gadolinium contrast. Phantom data was analyzed using a 3D breast protocol, and in-vivo data was analyzed from 3D imaging of a healthy volunteer's knee.

Methods: Our method of linear prediction is modified from Martin, et. al. [1] for 3D imaging. Our technique works in four steps. (1) K-space is multiplied by a ramp in the direction of truncation that weights k-space based on each line's distance from the origin. For our 3D application, x and y remain on one axis and are plotted against kz. Each kz line is then weighted accordingly. This now high-pass filtered data can more readily and accurately be used as inputs into an LP algorithm. (2) Each (x,y) line is independently autocorrelated in the kz direction. (3) These autocorrelated lines are then entered, along with the recursion order (number of previous kz lines used to predict the new line) into the Levinson-Durbin recursion algorithm. The predicted kz lines are added to the original kz lines. (4) The ramp multiplied previous to prediction is divided out of all the data. Finally, kz is Fourier transformed into image space providing the augmented number of images.

We applied this technique to a 3D breast imaging protocol using a phantom as well as to a 3D knee protocol in-vivo. Full kz data was collected to provide a standard for ideal data. Truncation followed by prediction occurred in post processing. The contrast breast protocol [2] includes: 3D spectral-spatial spiral acquisition, 32 slices/slab (full 32 kz acquisition), 256x256, FOV 20cm, flip angle 40, BW +/-125kHz, TE minimum, TR 38ms. For clinical use, only 20 kz lines are collected with this protocol and the remaining 12 are zero filled for a 32-slice reconstruction. Instead of zero filling, the lines were linearly predicted. The knee protocol [3] includes: 3D fat-saturated SPGR, 50 slices/slab, 256x256, FOV 14cm, flip angle 10, BW +/-31.25kHz, TE 4.2ms, TR 20.7 ms. The data was truncated to 30 kz lines and then predicted back out to 50. Data was collected using a 1.5T scanner (GE Healthcare, Waukesha, WI), with designated breast and knee coils (MRI Devices, Waukesha, WI).

Results: In Figures 1 and 2, image A is the reconstruction of the full kz acquisition without any truncation or prediction. Image B is the reconstruction when kz , the slice encode direction, has been truncated from 32 to 20 kz lines for the phantom images and 50 to 30 kz lines for the knee images. Figure 1 is data collected using the 3D breast protocol.

Figure 1. Phantom data collected using a 3D breast protocol. (A) full kz data (B) image from truncated kz (C) predicted image from truncated data. A,B,C are on the same windowing scale. (D)subtraction image of truncated data image from original image. (E) subtraction image of predicted image from original image. E,D are windowed on the same scale.

Notice the bar artifacts in the truncated image (B, arrow). This is a ringing artifact from an adjacent slice that has strong signal in that position. The prediction algorithm significantly reduces this artifact. The difference signal is notably stronger in the truncated/original difference image (D) than in the LP/original difference image (E). Linear prediction effectively corrected truncation artifacts caused by the clinically applied breast protocol. In Figure 2, which is windowed to show the artifact, notice the ringing effects from truncation near the cartilage (B,arrows). Since truncation is in kz, the ringing is not from the x-y plane but rather from adjacent slices. Image C is the linearly predicted data in which the ringing noted in B is corrected.

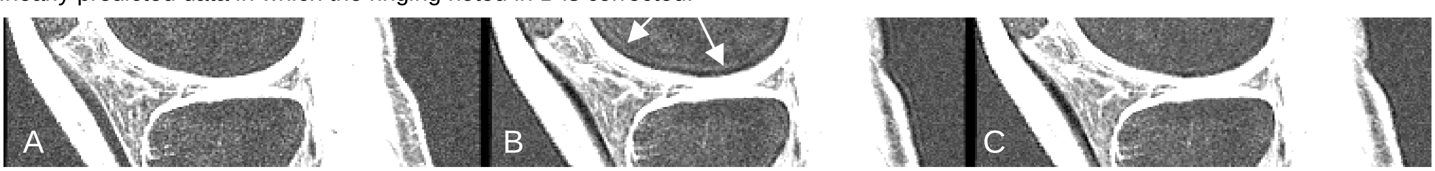

Figure 2. In-vivo knee data collected with 3D protocol. (A) image from full kz data (B) image from truncated kz (C) image from predicted kz. A,B,C are on the same windowing scale.

Discussion: Linear prediction can significantly reduce Gibbs ringing in the slice encode direction. In 3D breast imaging, not all kz lines are collected due to contrast enhancement time constraints. As demonstrated by phantom imaging, resultant ringing in the z direction may be corrected with the proposed 3D linear prediction algorithm. In cartilage imaging, a tri-laminar appearance of cartilage has been noted as an effect of Gibbs ringing [4]. Linear prediction in kz, significantly reduces this artifact. Future research entails applying the algorithm to clinical 3D breast MR and knee imaging. The algorithm will also be applied to 3D functional MR, MRCP and MRA imaging.

References:

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