Correcting bSSFP Distortion near Metals with Geometric Solution Phase

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Target Audience Researchers and clinicians in fields such as image-guided surgery or therapy who require signal positioning accuracy near metals when employing balanced steady state free precession (bSSFP) MRI will benefit from this work.

Purpose Imaging with bSSFP in inhomogeneous B_0 magnetic fields suffers from various artifacts; banding artifacts were recently corrected with an exact geometric solution (GS) [1]. Geometric distortion is naturally minimized in bSSFP due to strong gradients and short repetition time, but noticeable distortion can occur near metals due to excessive off-resonant phase accumulation. Phase labeling for additional coordinate encoding [2] was demonstrated to remap distorted signal near metals in MR images using a displacement map [3]. The map was generated from the phase difference of two images with variable added phase applied along their frequency encoding (FE) axes. While the bSSFP signal phase does not seem synergistic with this technique due to its essentially binary phase, the GS phase varies continuously with the local field inhomogeneity. If the GS phase can be unwrapped, it may be used as a displacement map to correct mismapped signal in GS magnitude images. This results in a method for correcting distortion near metals in debanded bSSFP images without additional scanning requirements beyond the GS.

Methods A 1.5T Siemens Avanto scannner was used to image a water phantom consisting of a Lego™ building encasing a Zimmer™ (Warsaw, IN) Cobalt Chromium Molybdenum hip prosthesis stabilized by a polyethylene mesh cage (Fig.1a). Four 3D-TrueFISP (bSSFP) images were acquired with $\Delta\theta$ = 0°, 90°, 180°, and 270° respective phase cycling, α = 40°, TE/TR = 2.3/4.6ms, receiver bandwidth BW = 558 Hz/pixel, and 256/168/160 matrix size and 1.2/1.2/1.2 mm voxel size along frequency/phase/slice directions. The GS was computed on the complex data as described in [1]. The GS phase was unwrapped using a Matlab™ implementation of Costantini's 2D phase unwrapping based on minimum network flow [4]. The unwrapped phase φ, the echo time TE, and BW allowed computation of a displacement map $\Delta y_{pix} = \varphi / (2\pi \cdot TE \cdot BW)$ for remapping signal. Sub-pixel data interpolation was achieved by expanding this map, smoothing it, and then remapping pixels in an expanded GS magnitude image. The final rebinned image has both bands and distortion removed.

Results Fig.1b) shows the binary nature of one bSSFP phase image, and the Fig. 1e) corresponding magnitude image indicates that the distortion-sensitive FE direction is vertical. Fig. 1c) shows the wrapped but continuously varying GS phase, while the corresponding GS magnitude image in Fig 1f) indicates the observably distorted regions with arrows. The d) unwrapped GS phase image exhibits some problems in signal loss regions where phase varies rapidly. Regardless, arrows in Fig 1g) indicate that this phase may be used to remove bSSFP image distortion near metals.

Discussion The main benefits of this method are that no extra scans and minimal processing time are needed for its computation. It is interesting to note that an additional phase reference scan is unnecessary. Only areas of very high field inhomogeneity display distortion, where significant phase accumulates. Phase reference error is less than 2π, and relatively insignificant in these regions. Phase unwrapping is an undesirable requirement of this technique, but the continuity of the GS phase makes it relatively feasible in two dimensions.

Conclusion

The proposed technique can correct distortion in bSSFP imaging near metals without requiring additional scans beyond those needed for the GS.

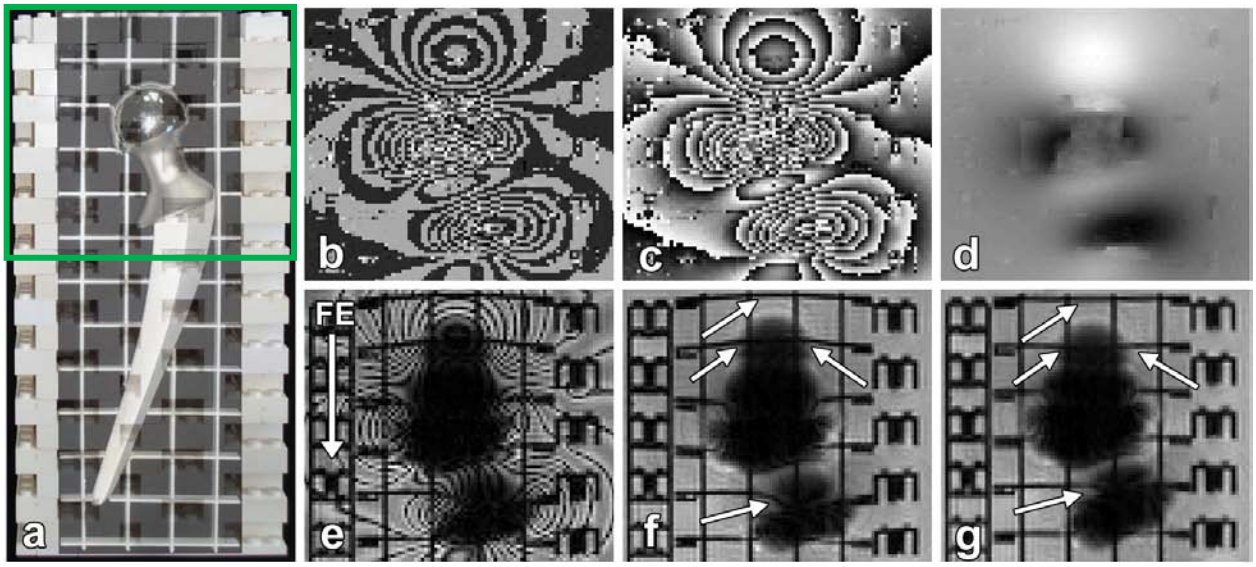

Fig. 1 a) Lego phantom has a CrCoMo hip prosthesis secured within by a polyethylene mesh cage. The green square delimits the image region. b) TrueFISP image phase. c) Geometric solution (GS) phase. d) Unwrapped GS phase. e) TrueFISP image magnitude. f) GS magnitude. g) Distortion correction of f) using d). White arrows indicate the distortion-sensitive frequency encoding direction, and emphasize regions where distortion is corrected.

References

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