Motion-Robust Super-Resolution Reconstruction of Fetal Brain MRI

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Purpose

Fetal MRI is increasingly seen as an excellent complement to prenatal ultrasound in the resolution of ambiguous ultrasound findings and is potentially a powerful non-invasive screening tool for precise evaluation of high-risk pregnancies. Nevertheless, fetal MRI is limited to two-dimensional acquisitions by the low signal available from the small fetal brain, and by intermittent fetal motion that disrupts spatial encoding necessary for advanced three-dimensional volumetric MRI. Fast imaging sequences, such as half-Fourier acquisition single-shot fast spin echo (SSFSE), are used to obtain high-quality high-resolution 2D slices. These slices are acquired as snapshots in a fraction of a second, thus freezing the motion of the fetus. The acquired scans represent anatomic details in the slice plane views, however, due to fetal motion between slices and the thick slice acquisitions necessary to maintain high signal-to-noise ratio (SNR), the out-of-plane views only poorly capture the 3D structure of the fetal anatomy. Three-dimensional volumetric fetal brain MRI has been shown to be feasible through inter-slice motion correction and volume reconstruction [1-5]. The earlier techniques were based on iterations of slice-to-volume registration and scattered data interpolation (SDI) [1-3], however more recently the problem has been addressed through a generic mathematical formulation inspired by the concept of super-resolution image reconstruction [4]. This formulation relies on a forward model of slice acquisition which involves a model of motion, slice profile, and signal acquisition; and provides a high-resolution estimate of the underlying anatomy through solving an inverse problem. The concept of motion-robust super-resolution MRI is an extension of the previous attempts on super-resolution MRI [6,7] and has shown remarkable outcomes in applications such as fetal MRI. Although the mathematical concept is generic and can potentially lead to significant new advances in MRI of moving subjects, the methods are still new to the majority of the MRI community. The purpose of this multimedia educational poster is to review the mathematics of these methods and illustrate with visual examples how these methods can generate beautiful volumetric images of the tiny moving fetus. The problem will be considered from the physics of MRI viewpoint and future developments and further applications will be discussed.

Outline of Content

1. Introduction: Fetal MRI and MRI of moving subjects with no control on motion: very useful but very challenging;
    a. What is the current practice and what do the images look like?
2. Methods: Motion-robust Super-resolution MRI
    a. The method by illustration: fetal brain MRI – an exemplary application of motion-robust super-resolution MRI
    b. Mathematical details
    c. K-space interpretation
3. Discussion: Resolution limits in MRI
    a. The trade-off between spatial resolution, signal-to-noise-ratio, contrast, and acquisition time.
    b. How the sensitivity of MRI to motion affects the achievable spatial resolution and poses performance limits.
    c. A review of literature on super-resolution MRI with discussion.
4. Conclusion: Future work and further applications

Summary

Motion-robust super-resolution MRI is a recently developed approach that has shown remarkable outcomes in fetal MRI. The approach has been built upon a solid mathematical framework that involves an MRI slice acquisition model and is solved through error minimization. Figure 1 shows a sample outcome of fetal brain MRI reconstruction using this approach; Fig. 1(a) shows slices of an original SSFSE scan obtained from a 1.5-T Philips MRI scanner, Fig. 1(b) shows the average of eight SSFSE scans acquired for the fetus in one scanning session, and Fig. 1(c) shows the volume reconstructed from the eight SSFSE scans after applying motion-robust super-resolution volume reconstruction.

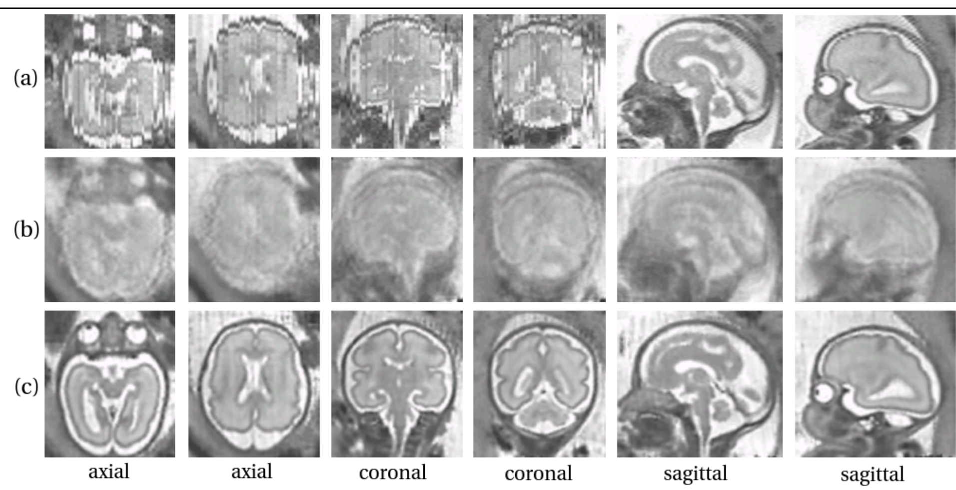

Fig. 1: Super-resolution volumetric reconstruction of fetal brain MRI from multiple SSFSE scans; two axial, two coronal, and two sagittal slices are shown for each image; (a) is one of the original SSFSE scans acquired in the sagittal plane of the fetus, (b) is the initial volumetric estimation of the fetal MRI by averaging the original SSFSE scans, and (c) is the reconstructed volumetric image obtained from motion-robust super-resolution volume reconstruction.

References

[1] Jiang et al. TMI 26(7):967–980, 2007; [2] Rousseau et al. Academic Radiology 13(9):1072–10; [3] Kim et al. IEEE TMI 29 (1):146 – 158; [4] Gholipour et al. IEEE TMI 29:1739-58, 2010; [5] Kuklisova-Murgasova et al. Medical Image Analysis 2012 [6] Greenspan. Computer Journal 52:43-63; [7] Plenge E. et al. MRM 2012.