Fan-beam Projection Image Acquisition using MRI
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Introduction
Motivation:
• Real-time image acquisition for interventional MRI.
• Possible with MRI:
  • Fast acquisition of parallel projection images.
  • Lack of perspective distortion similar to X-ray fluoroscopy.

Idea:
• Using the Fourier-Slice theorem to identify the section of the k-space to which a fan-beam projection is contributing.
• Using the MRI to sample only this section and create a fan-beam projection.

Goal:
• Create fan-beam projections with MRI using a minimal number of parallel projections.

Materials and Methods

- Fan-beam projection in Fourier space:
  • According to the Fourier-Slice theorem the information for a fan-beam projection lies in a wedge in Fourier Space with the fan-angle (see Fig. 1).
  • Creating a fan-beam projection (see Fig. 2):
    1. Sampling this wedge by acquiring lines through the origin with the MRI followed by an inverse Fourier transform gives a stack of parallel projections.
    2. Use rebinning formulas to find the ray in the parallel projection stack:

      \[ \theta = \gamma + \beta \]

      \[ s = D_{si} \cdot \sin \gamma \]

      • where \( \gamma \) is the half fan-angle, \( \beta \) the angle between the central ray and the coordinate axis and \( D_{si} \) is the source to isocenter distance. The rotation angle of a detector acquiring parallel beam is described by \( \theta \) and \( \beta \) is the respective pixel.

    1. Using linear interpolation to obtain the value of the fan-beam projection.

- Undersampling the wedge in K-space:
  • The acquisition of one parallel projection for each fan-beam pixel is referred to as full sampling (see Fig. 3A).
  • Highly redundant data is acquired!
  • Reducing the amount of acquired parallel projections:
    • Investigate undersampling factors with equiangular spacing.
    • The outer as well as the central ray are always acquired.

Evaluation on:
• A slice of an X-ray and MRI sensitive head phantom.
• A ray-driven fan-beam forward projection is used as ground-truth (GT).

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Results and Discussion

- Qualitative evaluation: Fig. 3 shows that the resampling error is nearly constant down to 15 projections (Fig. 3B). Using fewer projections increases the error.
- Quantitative evaluation: In Fig. 3D the absolute error metrics w.r.t to the GT projection of the different undersampling factors are shown.

Conclusions
• We have shown that the MRI can acquire projection images with perspective distortion, while the k-space sampling is minimal.
• We have only investigated undersampling of the wedge using fewer parallel projections, undersampling along the line could give further improvement in acquisition time.
• Adapting the minimal k-space sampling to cone-beam enables for fast acquisition of projection images with the same perspective distortion as angiography systems.
• Minimal k-space sampling allows for interventional MRI projection image acquisition.