4D-MRI using Internal Surrogates

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Strategies for 4D-MRI

Real time 4D-MRI
- ultra-fast 3D MR sequence
- fast gradient, multi-coils, parallel processing
- inadequate image quality (3-4 mm, 1.5 s/f)

Retrospective 4D-MRI
- fast 2D MR sequence
- breathing signal (surrogate)
- adequate image quality (1.5x1.5x3 mm, 0.3 s/f)

Retrospective 4D-MRI
► Fast 2D cine MR
► Multiple slices
► Cine duration > 1 cycle
► Frame rate: ~3 f/s
► Slice thickness: 3-5 mm
► Pixel size: 1-2 mm

Image Acquisition

Respiratory Signal
► Surrogates
  - External
  - Internal/Image-based
► Signal processing
► Phase determination

Internal/image-based Surrogates

- Implant markers
- Diaphragm
- Air content
- Lung area
- Lung density
- Fourier transform
- Body area (axial, sagittal)
- Normalized cross correlation
- Deformable image registration

Fast MR Sequences

- TrueFISP/FIESTA (balanced steady state gradient echo)
  - T2*/T1, sensitive to fluid, band artifacts from long TR

- HASTE/SSFSE (single shot fast spin echo)
  - T2, good CNR, signal decay from lung echo train, blurring

- FLASH/Fast SPGR (fast spoiled gradient echo)
  - T1 (poor), tumor hypo-intensity

- EPI (echo-planar imaging)
  - GE-EPI (T2*), SE-EPI (T2), IR-EPI (T1)
  - susceptibility, ghosting, chemical shift, fat suppression

Fast MRI: Examples
Diaphragm as Surrogate


Slice Body Area (SBA): Axial

Slice Body Area (SBA): Sagittal

- Respiratory motion is mostly in SI and AP directions
- Potentially better correlation with tumor motion

Axial SBA ~ RPM: Example

Axial SBA ~ RPM: Summary

- Good correlation in the abdomen (R=0.94).
- Phase shifts observed in the lung in some patients.
**Sagittal SBA: Examples**

**Sagittal SBA ~ Motion Tracking**
- Respiratory signal (SBA v.s. ROI tracking)
- Motion tracking: cross-correlation algorithm

**Sagittal SBA ~ Motion Tracking**
- 7 Subjects, 5 single slice, 2 multi-slice
- Small phase difference in peaks (5.8%)

**Surrogate: Fourier Transform**
- 10 Subjects, 2 min scan, sagittal / coronal
- Small phase difference (~3.1 ± 4.8%)
- High correlation ($r^2=0.97±0.02$)

**Validation: FT ~ Tracking**
- 10 Subjects, 2 min scan, sagittal / coronal
- Small phase difference (~3.1 ± 4.8%)
- High correlation ($r^2=0.97±0.02$)
Validation

4D-MRI: Patient Example

- Tumor CNR: 20.1 in 4D-MRI, 2.5 in 4D-CT.

Summary

- 4D-MRI using internal surrogates is feasible.
- Slice body area and Fourier Transform are potential robust internal respiratory surrogates.
- Validation is essential for using internal respiratory surrogate.

4D Digital Human Phantom

4D-MRI for lung?

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