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SPATIAL AND SPECTRAL ANISOTROPY IN HARP IMAGES: AN AUTOMATED APPROACH

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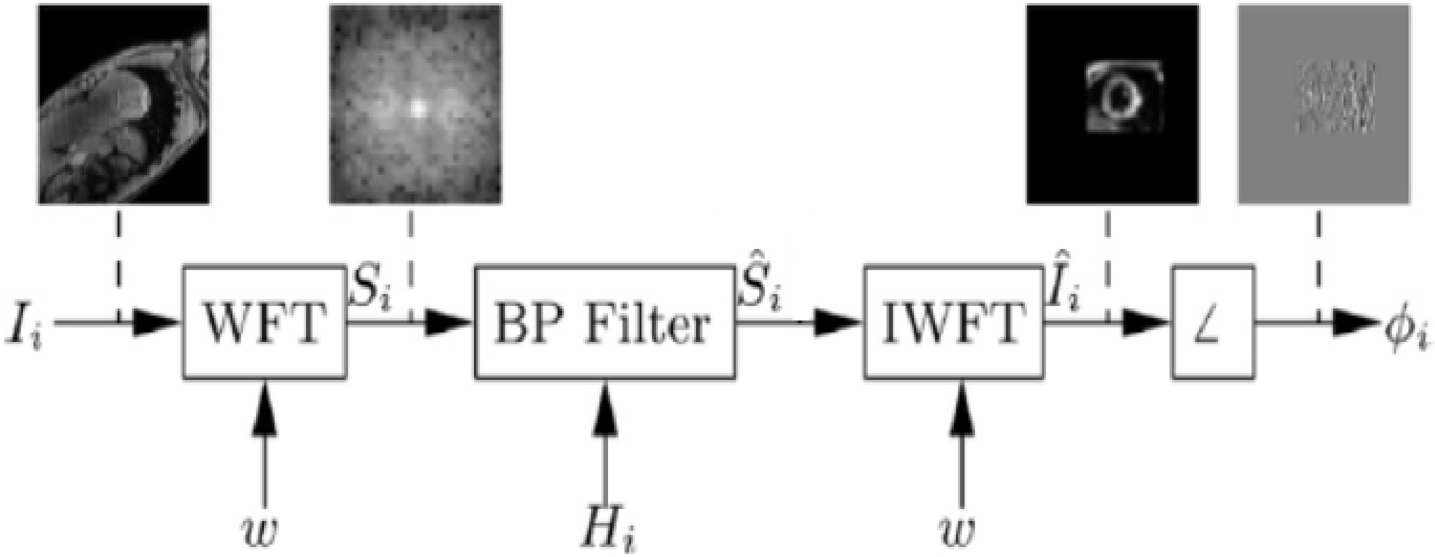
Introduction

- A HARP based method is presented for robust and accurate strain estimation in Tagged Magnetic Resonance Imaging.
- Spectral interference derived from nonhomogeneous deformation of the stripe pattern.
  - Joint design for both windowing and filtering stages
- Development of a full automated processing pipeline
  - Parameters estimated directly from data and DICOM headers.

Introduction

- Typical flowchart for the harmonic phase extraction from Tagged Magnetic Resonance Images.



- Window (w) and filter (H) designs are key issues.
- Common framework under anisotropy assumption

Introduction: State Of The Art

Reference	Contributions	Window Design	Band-Pass Filter
Osman, 2000	Harmonic phase related to true motion	Full FT	Smooth ellipse. Long axis placed over stripe
Cordero-Grande, 2011	Smooth local phase estimation	Isotropic gaussian WFT	Circumferential filter at the maximum spectra
Fu, 2013	Tag pattern properties extraction	Variable window shape	2D thresholding
Cordero-Grande, 2015	Robust LAD reconstruction	WFT for multiple orientations	Less sensitive to filtering design

- The assumption of anisotropy leads to a fully automatic motion estimation tecnique avoiding spectral interferences without losing information.

Materials

Accuracy on synthetic data (MR-C). Reproducibility on real data (MR-T).

Sequence	MR-Tagging	MR-Cine
Pixel Spacing	1.33 mm	1.25 mm
Slice Thickness	8 mm	8 mm
Temporal phases	16	30
Tag Spacing	7 mm	None
Tag Orientation	0-180 deg	None
Repetition Time	6.018 ms	3.325 ms
Echo Time	3.634 ms	1.663 ms
Flip Angle	10 deg	45 deg

- Heart motion estimated on MR-Cine by free-form deformations.
- Undeformed Tagging modulation added and deformed, raising a ground-truth sequence (accuracy).
- Reproducibility measured as tensor difference from different stripe sets.

Methods

- The windowing technique is equivalent to apply a WFT along the stripe direction combined with a full FT on the perpendicular one.

- The analysis window is designed as:

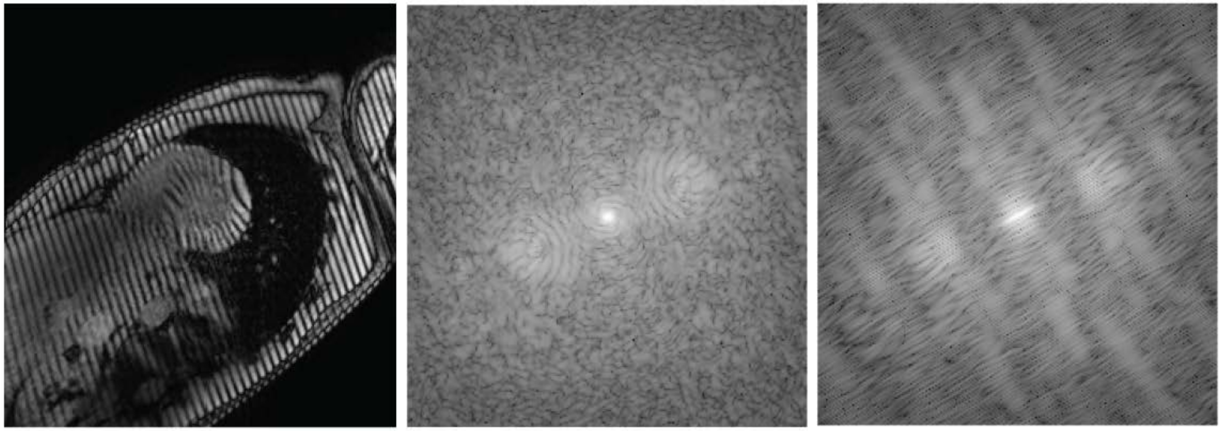
$$w(\mathbf{x}) \propto e^{-\frac{s^2}{2\sigma^2}}$$

where s stands for distance to the straight line defined from the nominal tag orientation as read from the DICOM header.

- Rapid tapering in the modulation direction with no attenuation in the orthogonal direction (σ set as nominal tag spacing).

Methods

- Spectral stretching orthogonally to the modulation direction.



(a) MR-T at ES (b) Isotropic WFT (c) Anisotropic WFT

- Spectral peaks retrieved with a Gaussian filter.
  - Band-pass filter on the modulation direction and all-pass filter over the perpendicular direction.
- Filter bandwidth estimated by Otsu's thresholding method.
  - 99% of the projected foreground over the modulation direction must fall within the effective bandwidth of the band-pass filter.

Validation

- After inverse WFT, local phase can be easily extracted. Standard procedures estimate the material deformation gradient tensor F.

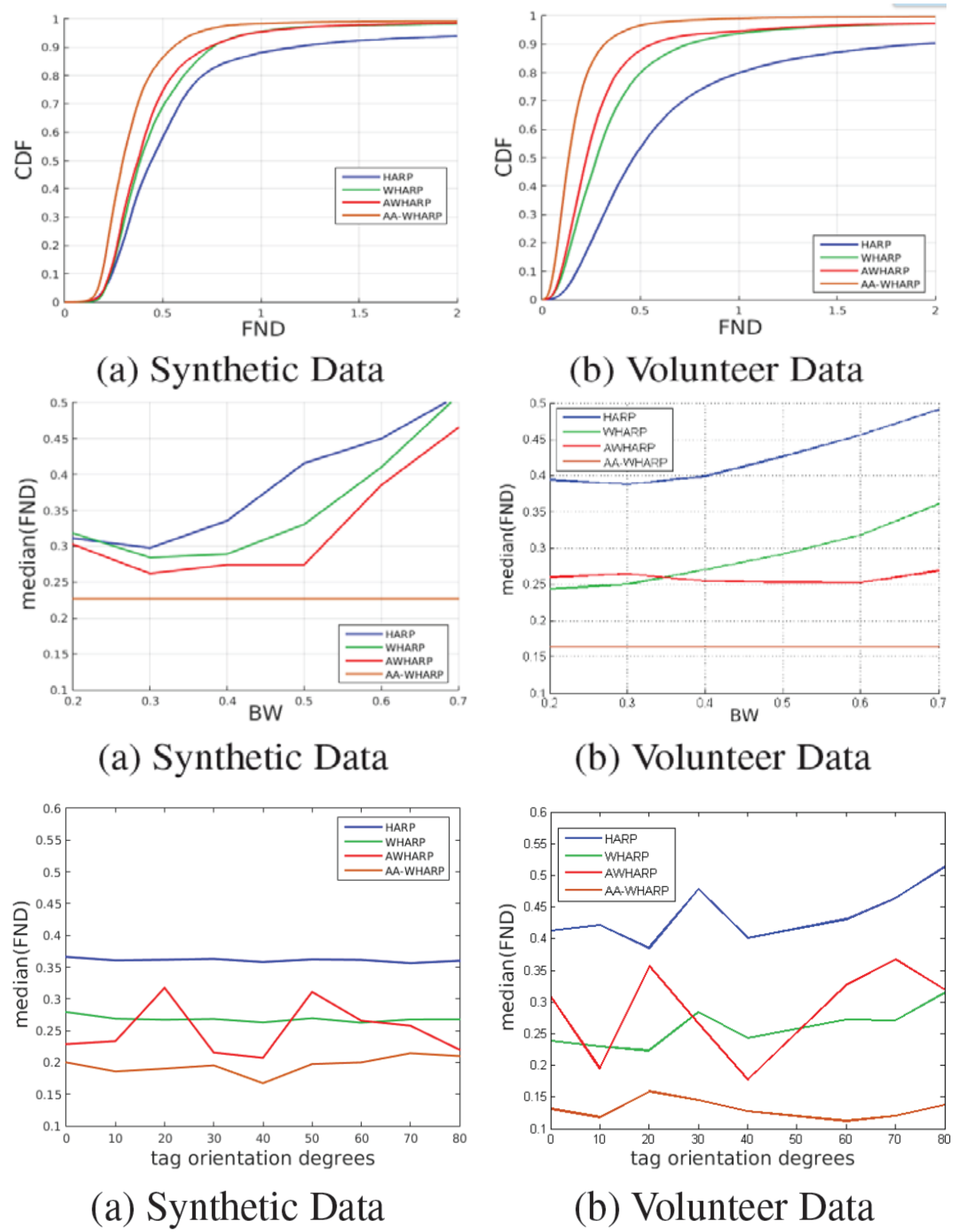
- Validation is carried out in terms of the variability of the estimated tensors at end-systole phase.

- Ideally, tensors should be equal for all datasets and procedures.
  - Frobenius norm difference (FND) distribution of the tensors:

$$FND(\mathbf{x}) = \sqrt{\sum_{m=1}^{2}\sum_{n=1}^{2}(\mathbf{F}^1_{mn}(\mathbf{x}) - \mathbf{F}^2_{mn}(\mathbf{x}))^2}.$$

Results

- Improved robustness and accuracy in tensor direct measures.
- Interferences, still remaining, giving rise to biased estimations.
- Automated filter estimation outperforms other HARP based methods.
- Method fairly independent from tag orientation.



(a) Synthetic Data (b) Volunteer Data

(a) Synthetic Data (b) Volunteer Data

(a) Synthetic Data (b) Volunteer Data

Conclusions

- A robust and reliable automatic motion estimation technique is achieved thanks to a joint anisotropic framework.
- Window design consists in an anisotropic Gaussian window which rotates according to nominal tag orientation.
- Spectral peaks undergo a significant stretching. Anisotropic filtering diminish spectral interference.
- The proposed pipeline, in addition, lends itself to a full automatic bandwidth estimation method.