MICCAI 2016 Athens GREECE
19TH INTERNATIONAL CONFERENCE ON MEDICAL IMAGE COMPUTING & COMPUTER ASSISTED INTERVENTION
October 17–21 2016
INTERCONTINENTAL ATHENAEUM • ATHENS / GREECE

Generation of Realistic 4D Synthetic CSPAMM Tagged MR Sequences For Benchmarking Cardiac Motion Tracking Algorithms

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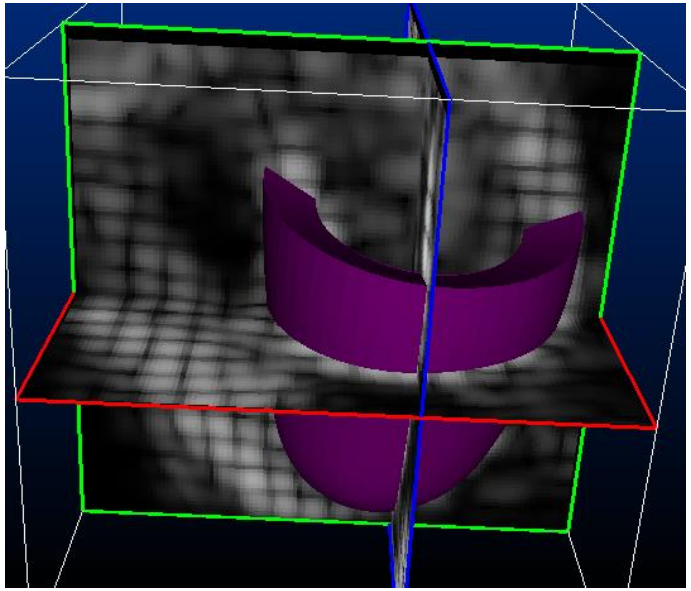
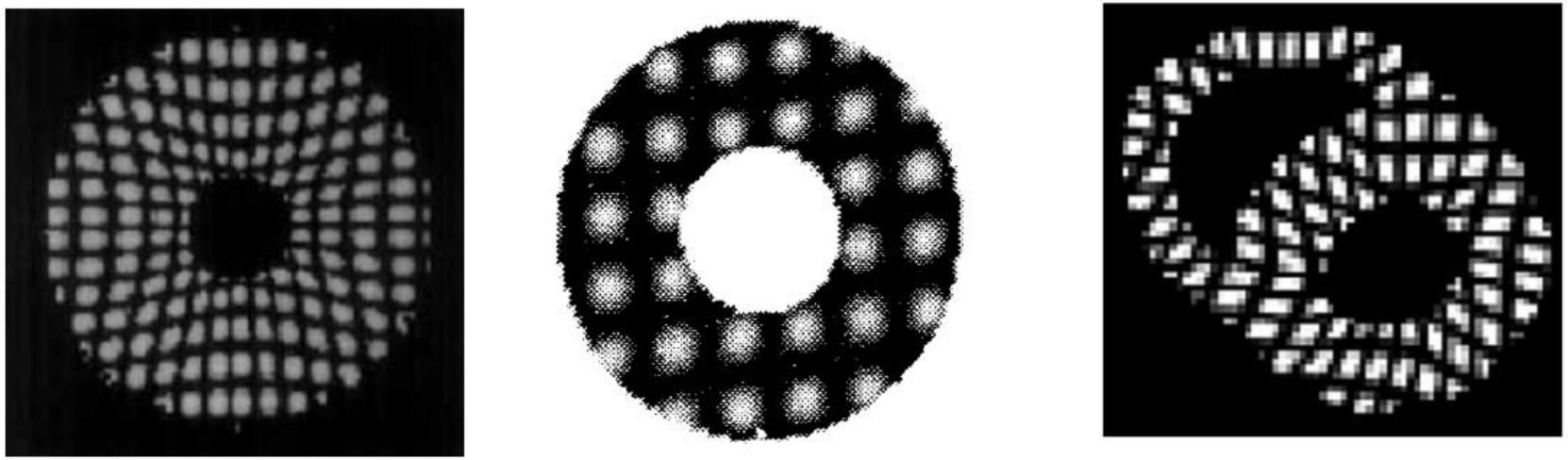
Introduction

- Tagged MR: gold standard for quantifying local cardiac deformations
- Its use in clinical practice is somewhat held back by a lack of reliable quantification tools
- Recently a number of tracking algorithms have been developed
- Need validation and benchmarking



State of the art in synthetizing cardiac tagged MR

- Little work has been done in simulating cardiac tagged MR
- Usually, warping an binary-like image by a motion model (kinetic or electro-mechanical)



(a) Crum *et al.* [2] (b) Waks *et al.* [3] (c) Sermesant *et al.* [5]

No background

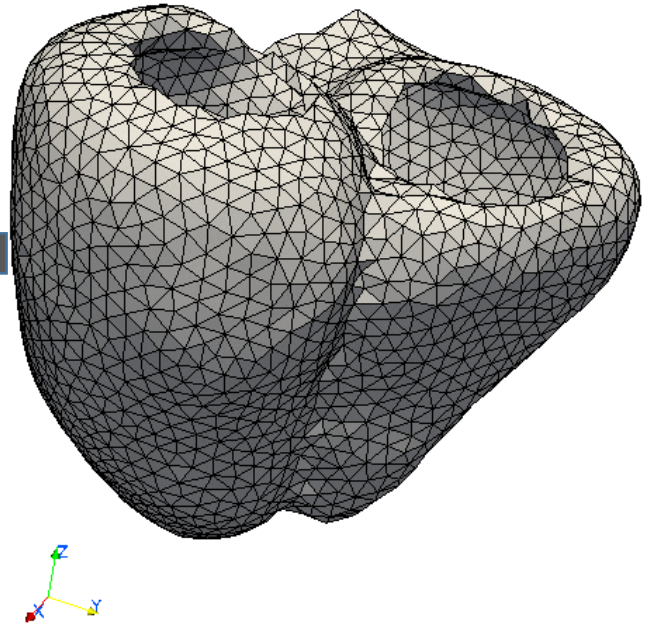
The proposed method

Inspired from [Alessandrini et al] and [Prakosa et al]

A real acquisition (template)

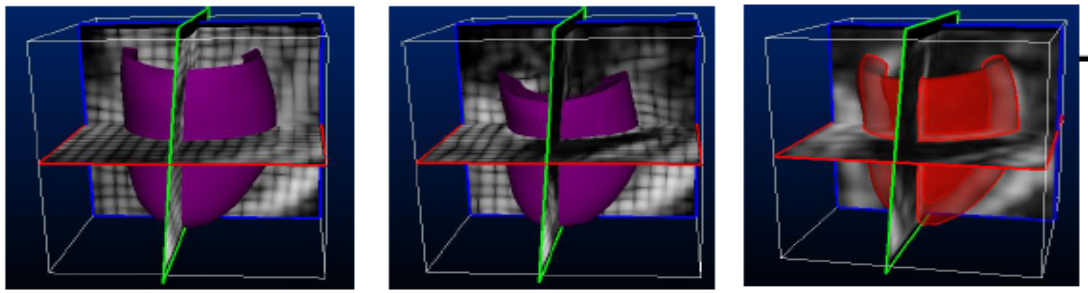
Combine

Cardiac deformations simulated by Electro-mechanical model

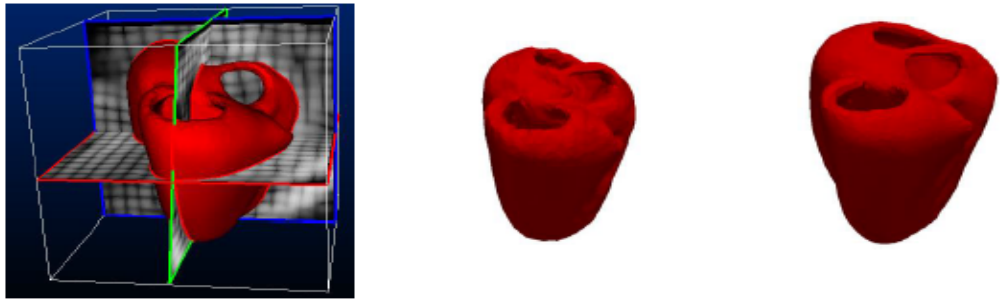


The pipeline

Section 2.1
Template sequence, segmenting & tracking



Section 2.2
E/M model, simulating myocardial deformations



End-diastole End-systole End-diastole

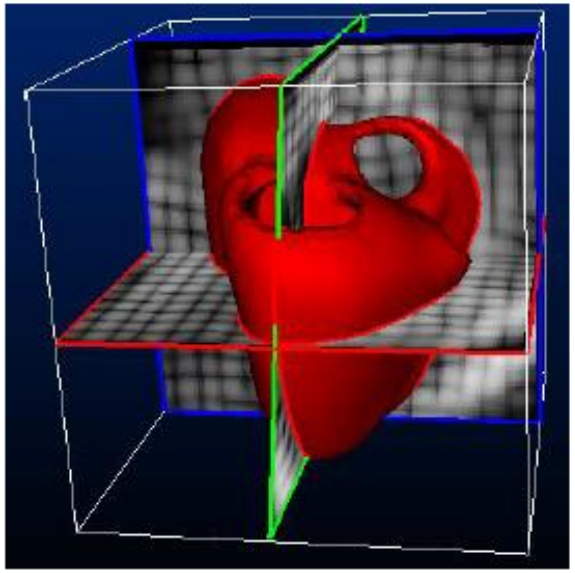
Section 2.3
Spatio-temporal alignment

Section 2.4
Image generation

Section 2.5
Correcting myocardium intensities

Simulating cardiac motion by Electro-mechanical model

Mapping a template bi-ventricle heart geometry to the image space
By thin plate spline transformation built upon the 17 AHA seg centers

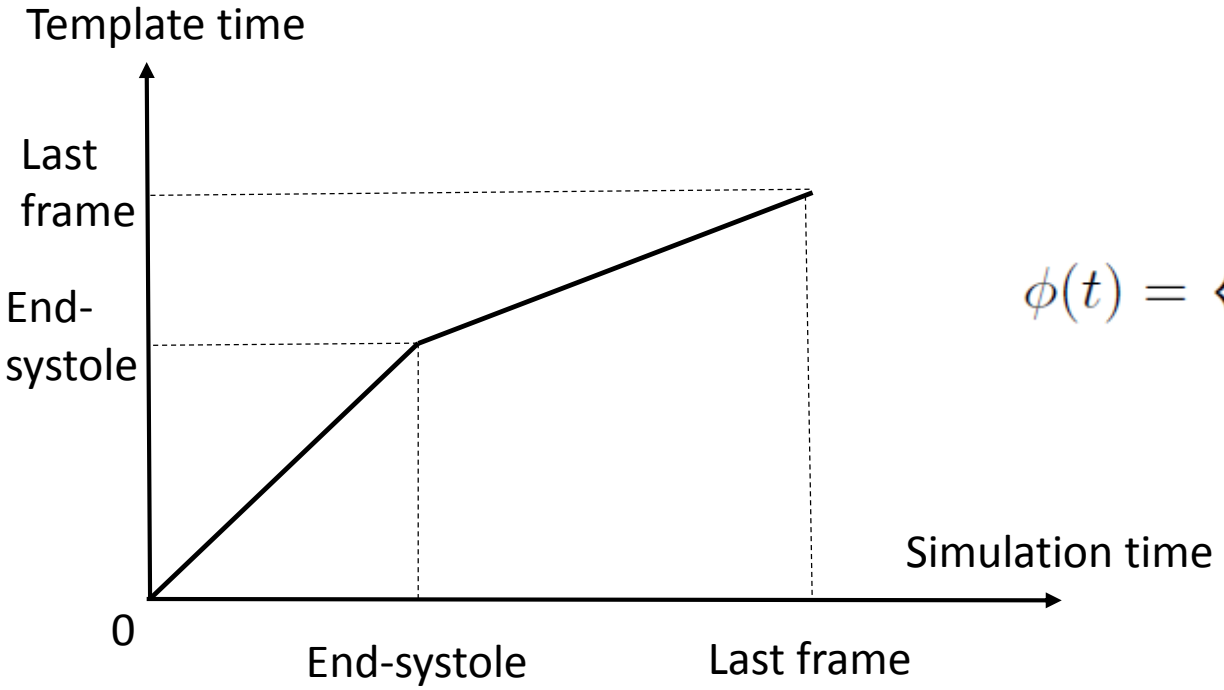


The E/M model:
1) Eletrical activations
2) Mechanical contraction

Marchesseau, S., Delingette, H., Sermesant, M., & Ayache, N. (2013).
Fast parameter calibration of a cardiac electromechanical model from medical images based on the unscented transform. *Biomechanics and modeling in mechanobiology*, *12*(4), 815-831.

Temporal alignment

- Map the k-th frame of the simulations to a continuous timing in template sequence
- Linear stretch/shrinking the systolic and diastolic time axes respectively



$$\phi(t) = \begin{cases} \frac{n_{img}^{es}}{n_{simu}^{es}} t, & \text{if } t \leq n_{simu}^{es} \\ \frac{\mathcal{N}_{img} - 1 - n_{img}^{es}}{\mathcal{N}_{simu} - 1 - n_{simu}^{es}} (t - n_{simu}^{es}) + n_{img}^{es}, & \text{otherwise} \end{cases}$$

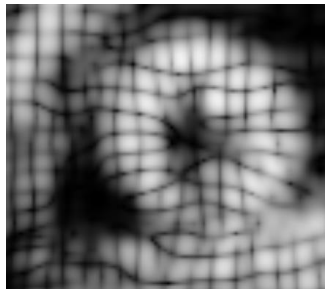
Spatial alignment

- Map a point in simulation space to a spatial location in template sequence

Naturally aligned

The first frame

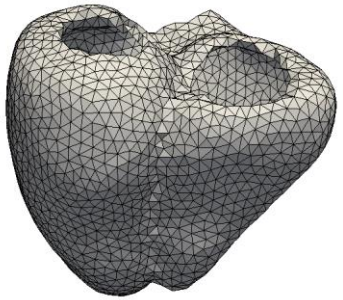
TPS 2



Thin-plate spline transforms

$$\mathbf{x}_{img} = \mathcal{T}_{\mathcal{M}_0 \to \mathcal{M}_{t_{img}}} \circ \mathcal{T}_{\mathcal{S}_{t_{simu}} \to \mathcal{S}_0}(\mathbf{x}_{simu})$$

TPS 1



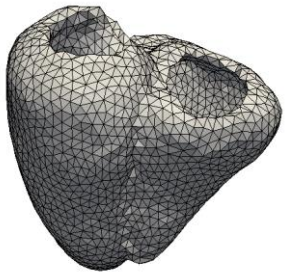


Image generation

- Following the image box information of the template (origin, spacing, axis direction, image size)
- Each pixel (x,t) is mapped to a corresponding position in the template, its intensity is computed by interpolating the template image there
- Generate a sequence of volumes (3D + t)

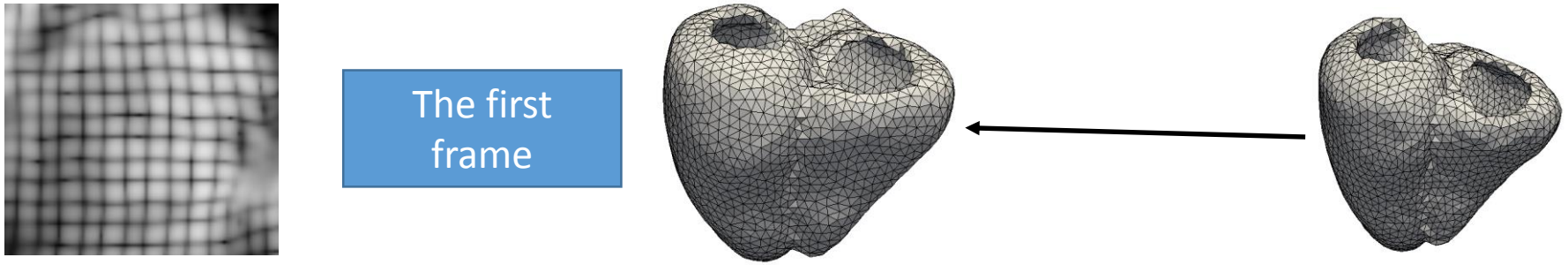
Correcting the intensities of myocardium

- <u>The spatial alignment relies on a tracked template</u>

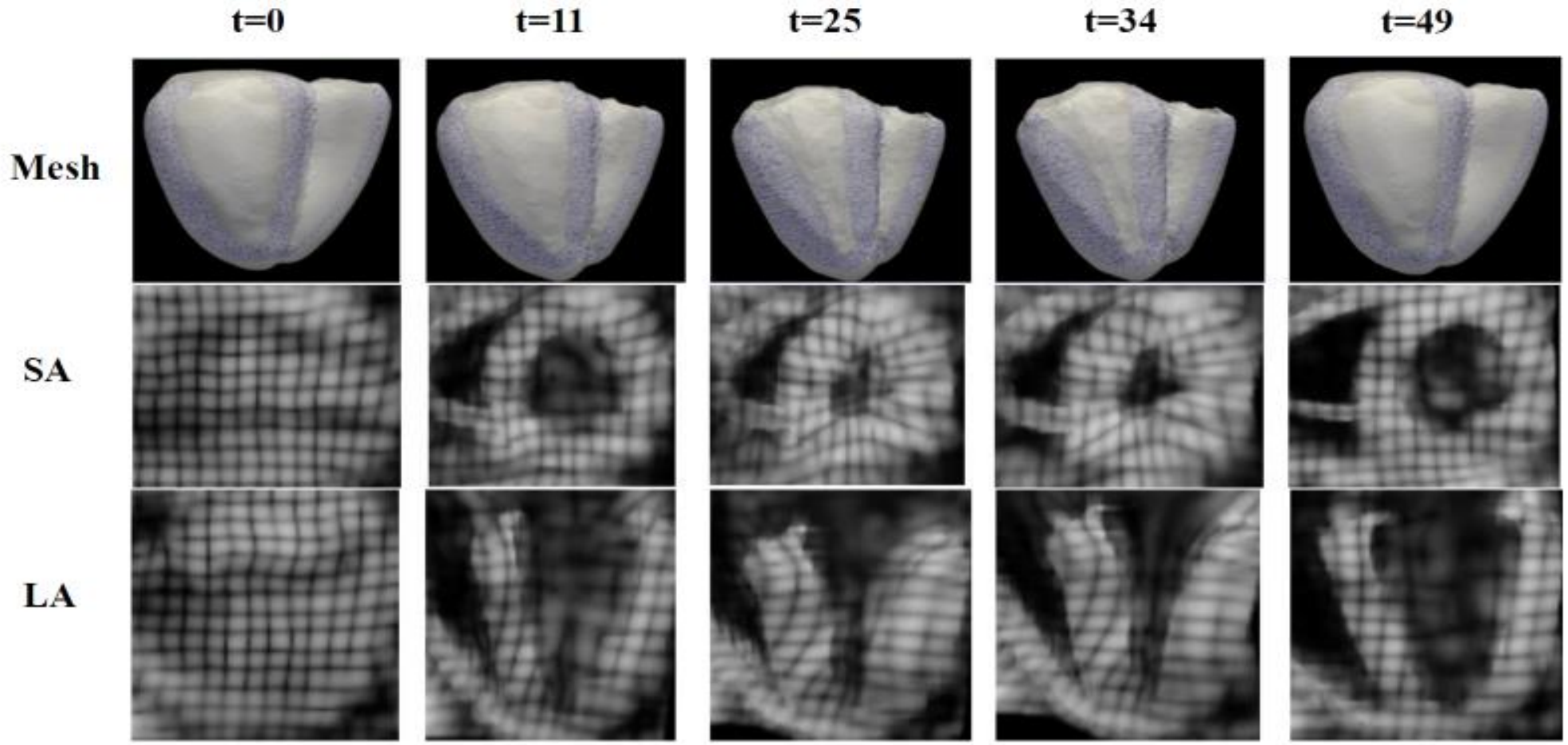
Tracking errors will introduce artifacts in the synthetic images, adding an apparent residual motion to the true motion given by the E/M model

- <u>We opt for correcting the intensities for the myocardium</u>

Myocardial intensities are all assigned from the first frame



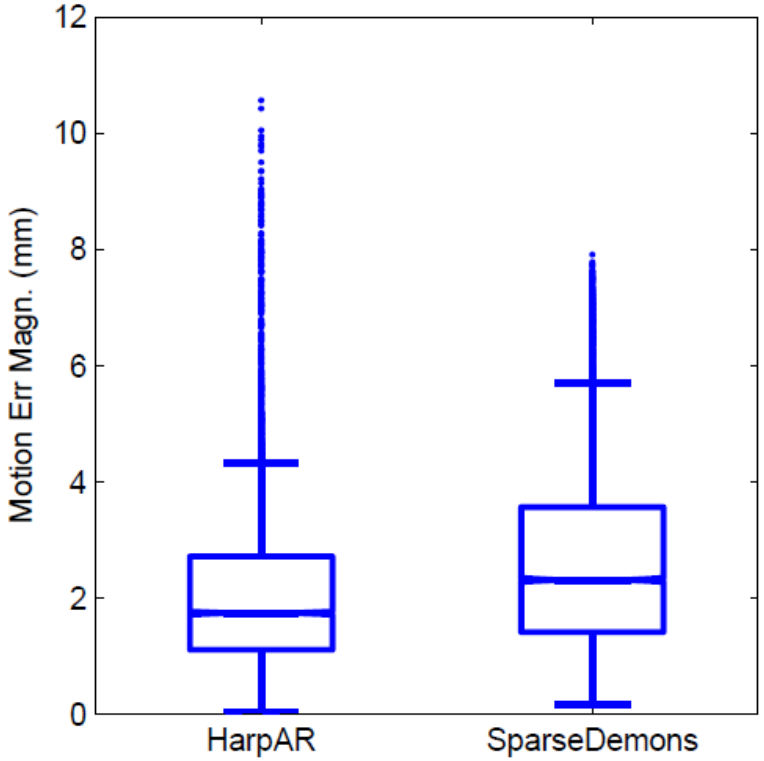
A normal heart (synthetic images + ground truth meshes)



Comparing two cardiac motion tracking algorithms

1) HARPAR 2) SparseDemons

Motion errors at end-systole



Discussion

- Since myocardium intensity is assigned from the first frame:
  1) no variation of intensity over time is modeled, i.e. no tag fading
  2) transition between myocardium/background is not smooth enough

- Only one normal heart is simulated, more pathological cases are needed. This is currently left to future work.

- The method relies on image warping. Using a physical MR simulator based on solving Bloch equation would produce better results.

Conclusion

- We proposed a pipeline that simulates realistic synthetic tagged MR images for benchmarking cardiac motion tracking algorithms
- We combined a real acquisition with an electro-mechanical model
- For the current stage, only a normal heart is simulated. The extension to pathological cases and more modalities (US, cine MR) are left to future work.

Thank you for your attention!

PHILIPS

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