Combination of Markerless Surrogates for Motion Estimation in Radiation Therapy

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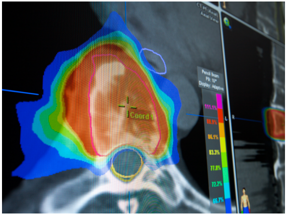
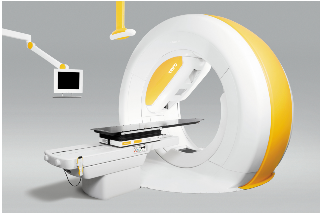
Motivation

External Beam Radiation Therapy

- Planning CT → Optimized dose distribution
- Respiratory motion → Target volume displacement

! Potential survival of malignant cells





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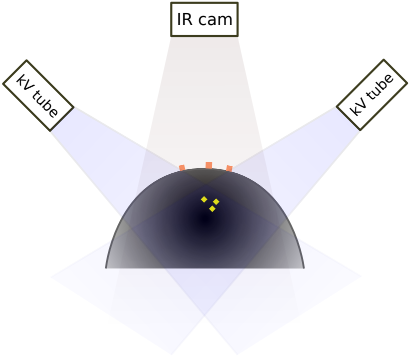
Motion Estimation

Clinical State of the Art

- Marker Tracking
  - × Control points based
  - × Only sparse deformation



Motion Estimation

Clinical State of the Art

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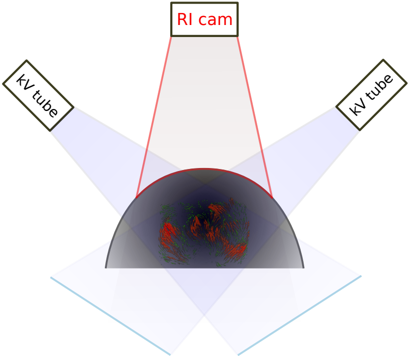
Novel Approaches

- Range Imaging
  - ✓ Dense surface information
  - ✓ Non-intrusive
- Fluoroscopy
  - ✓ Image-based signal
- Internal motion models
  - ✓ Dense internal deformation



Outline

- Motion Estimation
  - Motion Models
  - Correlation & Prediction
  - Multi Surrogate Approach
- Results & Discussion
- Outlook

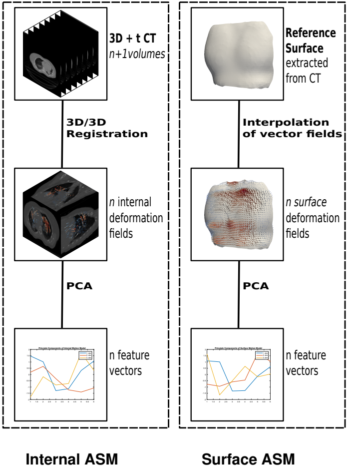
Motion Models

Internal Motion

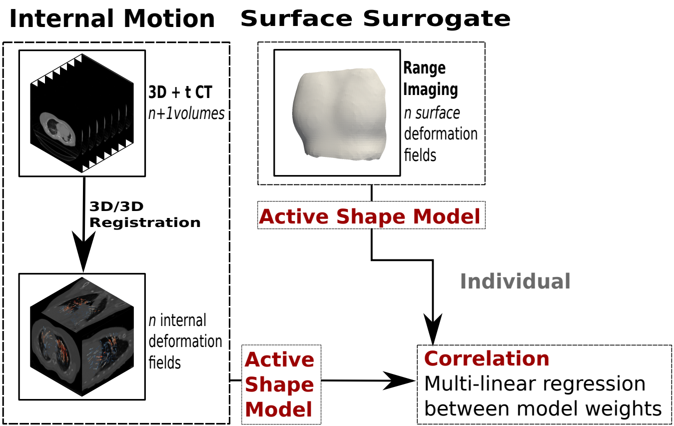
- Non-rigid 3D/3D registration w.r.t. reference phase t_{ref}
- Cropping to internal ROI

Surface Motion

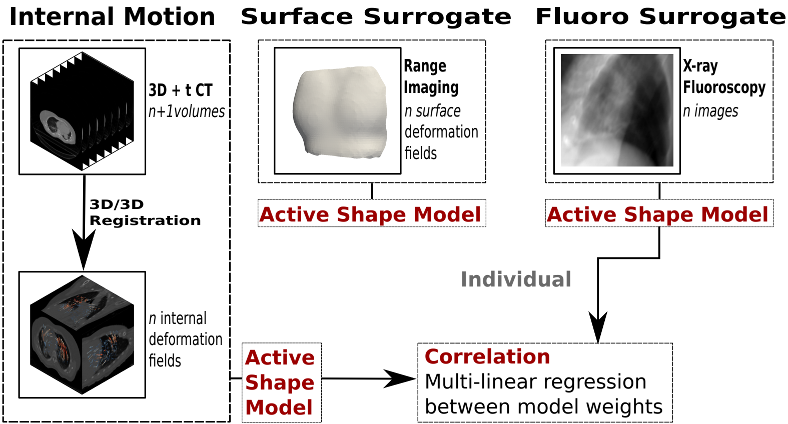
- Surface extracted from 3-D data set
- Deformation fields $\boldsymbol{d}_i$ interpolated at mesh-vertices



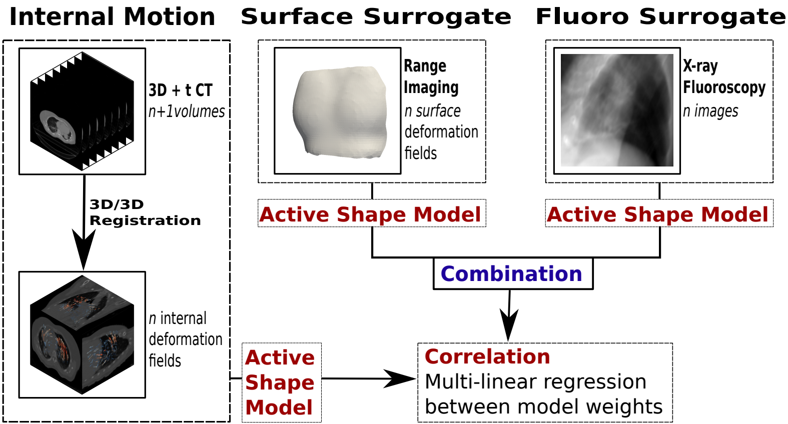
Framework Overview



Framework Overview



Framework Overview



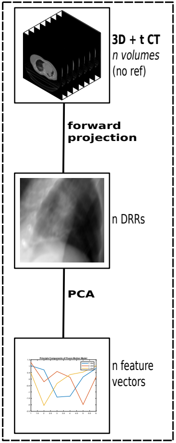
Fluoroscopy Surrogate Model

Preprocessing

- DRRs from volumetric CT data
- According to Vero kV beam geometry

Breathing Signal Extraction

- Linearized images
- PCA of the change in intensity
- First few principle component correlate highly with breathing phase



Multi-surrogate Approach

Motivation

- Combined information from range imaging and fluoroscopy
- Improve the estimation or compensate for one surrogate failing

Combination

- Concatenated feature vector
  $$\boldsymbol{\sigma}_{\mathrm{CB}_i} = \begin{bmatrix} \boldsymbol{\sigma}_{\mathrm{RI}_i} \\ \boldsymbol{\sigma}_{\mathrm{FL}_i} \end{bmatrix} \in \mathbb{R}^{(f_{\mathrm{RI}}+f_{\mathrm{FL}})\times 1}$$
- Regression matrix
  $$\mathbf{R}_{\mathrm{CB}} \in \mathbb{R}^{l\times(f_{\mathrm{RI}}+f_{\mathrm{FL}})}$$

Example:

$$\boldsymbol{R}_{\mathrm{CB}} \in \mathbb{R}^{3\times(2+2)}$$

$$\begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{bmatrix} = \boldsymbol{R}_{\mathrm{CB}} \begin{bmatrix} \sigma_{\mathrm{RI}_1} \\ \sigma_{\mathrm{RI}_2} \\ \sigma_{\mathrm{FL}_1} \\ \sigma_{\mathrm{FL}_2} \end{bmatrix}$$

Evaluation

Data

- Nine 4-D CT patient data sets
- Ten volumes each (voxel size: $0.97 \times 0.97 \times 2.5\,\text{mm}^3$)
- DRRs: detector with 1024×768 pixels and 0.39 mm pixel spacing

Experiments

- Correlation study on feature weights
- Leave-one-out-assessment of the estimation error w.r.t. ground-truth

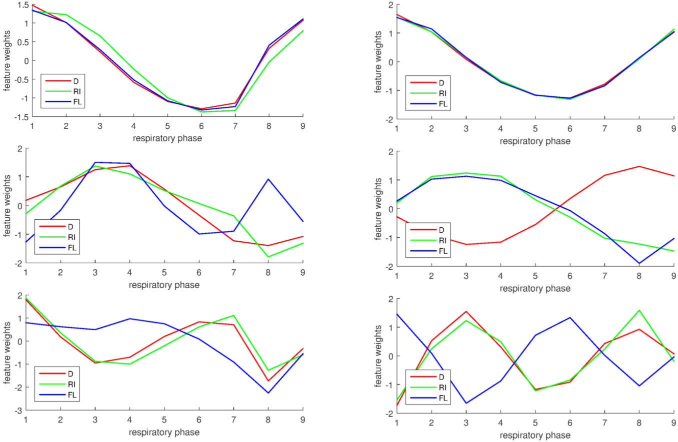
Results: Correlation

Pat3 | Pat9

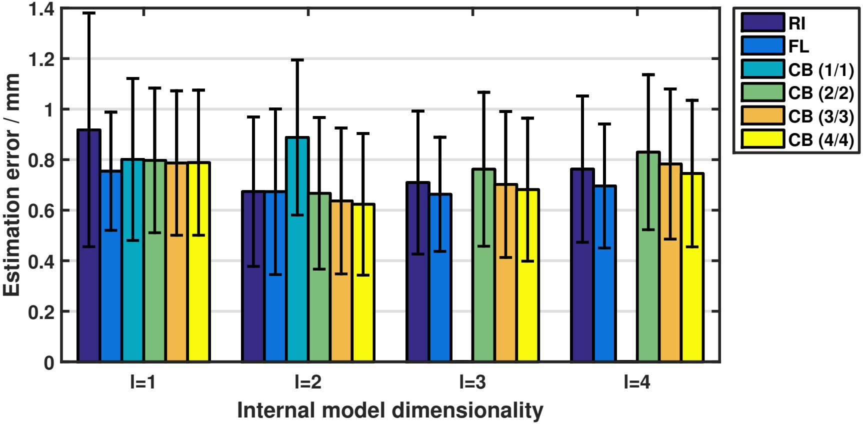
1. PC

2. PC

3. PC



Results: Estimation



reference mean: 2.31 ± 0.70 mm

Discussion

Single Surrogate

- Fluoro outperforms surface surrogate: 0.67 ± 0.33 mm for $l = 2$
- No improvement with higher internal model dimension

Combination Approach

- No consistent improvement
- $f_{\mathrm{RI}}, f_{\mathrm{FL}} = 1$: 1-D respiratory phase $\rightarrow$ Linearly dependent
- Best overall for $l = 2$ from (2+2) or higher combined features:

$$0.62 \pm 0.28 \text{ mm}$$

$\rightarrow$ Surrogate combination useful under certain circumstances

Outlook

Surrogate Extraction

- DR eliminates non-redundant information
- Sophisticated ways to extract mutually exclusive information

Data Acquisition & Training

- Training currently only done on 6 of 9 phases
  (necessity of leave-one-out approach)
  - × ASMs do not describe an entire cycle
  - ✓ Training on entire cycle
  - ✓ Prediction on another of the <u>same</u> patient

Thank you for your attention.

Questions?

LME