Combination of Markerless Surrogates for Motion Estimation in Radiation Therapy

CARS 2016

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Motivation

External Beam Radiation Therapy

- Planning CT $\rightarrow$ Optimized dose distribution
- Respiratory motion $\rightarrow$ Target volume displacement

! Potential survival of malignant cells
Motion Estimation

Clinical State of the Art

- Marker Tracking
  - Control points based
  - Only sparse deformation
Motion Estimation

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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 \( t_{\text{ref}} \)
- Cropping to internal ROI

Surface Motion

- Surface extracted from 3-D data set
- Deformation fields \( d_i \) interpolated at mesh-vertices
Framework Overview

**Internal Motion**

- 3D + t CT
- 3D/3D Registration
- n+1 volumes
- n internal deformation fields

**Surface Surrogate**

- Range Imaging
- n surface deformation fields
- Active Shape Model
- Multi-linear regression between model weights
- Individual

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**Fluoro Surrogate**
- X-ray Fluoroscopy
- n images
- Active Shape Model

**Individual**
- Correlation
  - Multi-linear regression between model weights

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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
  \[ \sigma_{CBi} = \begin{bmatrix} \sigma_{RIi} \\ \sigma_{FLi} \end{bmatrix} \in \mathbb{R}^{(f_{RI}+f_{FL}) \times 1} \]

- Regression matrix
  \[ R_{CB} \in \mathbb{R}^{l \times (f_{RI}+f_{FL})} \]

Example:
\[ R_{CB} \in \mathbb{R}^{3 \times (2+2)} \]
\[
\begin{bmatrix}
\phi_1 \\
\phi_2 \\
\phi_3
\end{bmatrix}
= R_{CB}
\begin{bmatrix}
\sigma_{RI1} \\
\sigma_{RI2} \\
\sigma_{FL1} \\
\sigma_{FL2}
\end{bmatrix}
\]
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 $1024 \times 768$ 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

1. PC

![Graph for Pat3](image1.png)

2. PC

![Graph for Pat9](image2.png)

3. PC
Results: Estimation

reference mean: $2.31 \pm 0.70$ mm
Discussion

Single Surrogate

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

Combination Approach

- No consistent improvement
- $f_{RI}, f_{FL} = 1$: 1-D respiratory phase $\rightarrow$ Linearly dependent
- Best overall for $l = 2$ from (2+2) or higher combined features:
  
  $0.62 \pm 0.28$ 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 same patient
Thank you for your attention.

Questions?