Incremental Dimensionality Reduction for Respiratory Signal Extraction From X-Ray Sequences

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Introduction
Guidance for Fluoroscopy

- Guidance of minimally invasive interventions
- X-ray fluoroscopy visualizes high-density structures well
- Overlays to visualize low-density structures of interest
- Pre-procedural creation of overlays, e.g. segmentation from CT, MR, ...
- Clinical applications
  - Cardiology
  - Electrophysiology
  - Abdominal interventions
Guidance for Fluoroscopy

State of the art: static overlays

- Information about 3-D structure of soft tissue
- Navigation help for the physician
- Inconsistency between overlays and live images due to
  - patient motion
  - cardiac motion
  - respiratory motion

Motion compensation for overlays using motion models

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Motion Compensation for Overlays
Motion Compensation for Overlays

Image Registration

Motion Estimates
Motion Compensation for Overlays

Surrogate Signal

Signal Extraction

Image Registration

Motion Estimates
Motion Compensation for Overlays

Image Registration → Motion Estimates → Real-time Motion Model → Surrogate Signal → Signal Extraction
Methods
Dimensionality Reduction for Respiratory Signal Extraction

Dimensionality Reduction
Recover underlying causes of image variation from the X-ray sequence by learning the relationship between images and causes.
Dimensionality Reduction

- Dimensionality reduction: \( X \in \mathbb{R}^{N \times M} \rightarrow x \in \mathbb{R}^{N \cdot M} \rightarrow y \in \mathbb{R}^{1} \)
- Learn mapping from data in unsupervised manner
- Preserve geometric properties in the embedding
- Major distinction: **Linearity**
  - Linear approaches: Principal component analysis, multidimensional scaling
  - Nonlinear approaches: Manifold learning, clustering
- Respiratory signal extraction from X-ray feasible with manifold learning²

Are linear approaches sufficient?

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Incremental Principal Component Analysis

- Maximizes explained variance of projected components
  \[ \max \sum_i \text{var}(y_i) \]

- Projection is restricted
  - Linear projection model \( y = Wx \)
  - Orthogonal dimensions \( w_0 \perp w_1 \perp \ldots \)

- Incremental version\(^3\) approximates \( W \) iteratively for each new \( x \)

Incremental Manifold Learning

- Preserve geodesic distance between images
- Geodesic distance approximated using neighborhood graph
- Incremental version saves unnecessary computations

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Evaluation
Evaluation Setup

Data

- 13 X-ray sequences of 76 to 465 images from animal studies
- Images of $1024 \times 1024$ pixels downsampled to $256 \times 256$ pixels
- Varying point of view and clinical devices
- Training phase of 40 images
- Number of neighbors in Isomap $k = 20$

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Compared Algorithms

- IPCA: incremental PCA (linear)$^5$
- INCISO: incremental manifold learning (nonlinear)$^6$

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Correlation with Diaphragm Tracking

- Tracking of the diaphragm
- Comparison with the y-coordinate of the diaphragm top
- Measure similarity using normalized cross-correlation $NCC_{\text{diaphragm}}$ (mean ± standard deviation)

<table>
<thead>
<tr>
<th>Method</th>
<th>$NCC_{\text{diaphragm}}$</th>
<th>Runtime [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPCA</td>
<td>0.93 ± 0.05</td>
<td>4.6 ± 1.1</td>
</tr>
<tr>
<td>INCISO</td>
<td>0.97 ± 0.02</td>
<td>22.7 ± 12.0</td>
</tr>
</tbody>
</table>

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7 Marco Bögel et al. “Diaphragm Tracking in Cardiac C-Arm Projection Data”. In: Bildverarbeitung für die Medizin. 2012, pp. 33–38
Example Respiratory Signal from X-Ray Sequence

- Diaphragm tracking
- IPCA
- INCISO
Conclusion
Conclusion and Outlook

- Real-time respiratory signal extraction from X-ray sequences
- Linear and nonlinear dimensionality reduction to learn breathing manifold
  - In theory, nonlinear relationship between respiratory motion and image intensities
  - Tradeoff between accuracy and speed
- ⇒ Nonlinear dimensionality reduction is superior
Conclusion and Outlook

- Real-time respiratory signal extraction from X-ray sequences
- Linear and nonlinear dimensionality reduction to learn breathing manifold
  - In theory, nonlinear relationship between respiratory motion and image intensities
  - Tradeoff between accuracy and speed
  ⇒ Nonlinear dimensionality reduction is superior
- Future work
  combination with a motion model to enable motion compensation
Thank you for your attention!