RIGID LENS

Locally Rigid Approximations of Deformable Registration for Change Assessment in Thorax-Abdomen CT Follow-Up Scans

Sonja Jäckle[1] sonja.jaeckle@mevis.fraunhofer.de

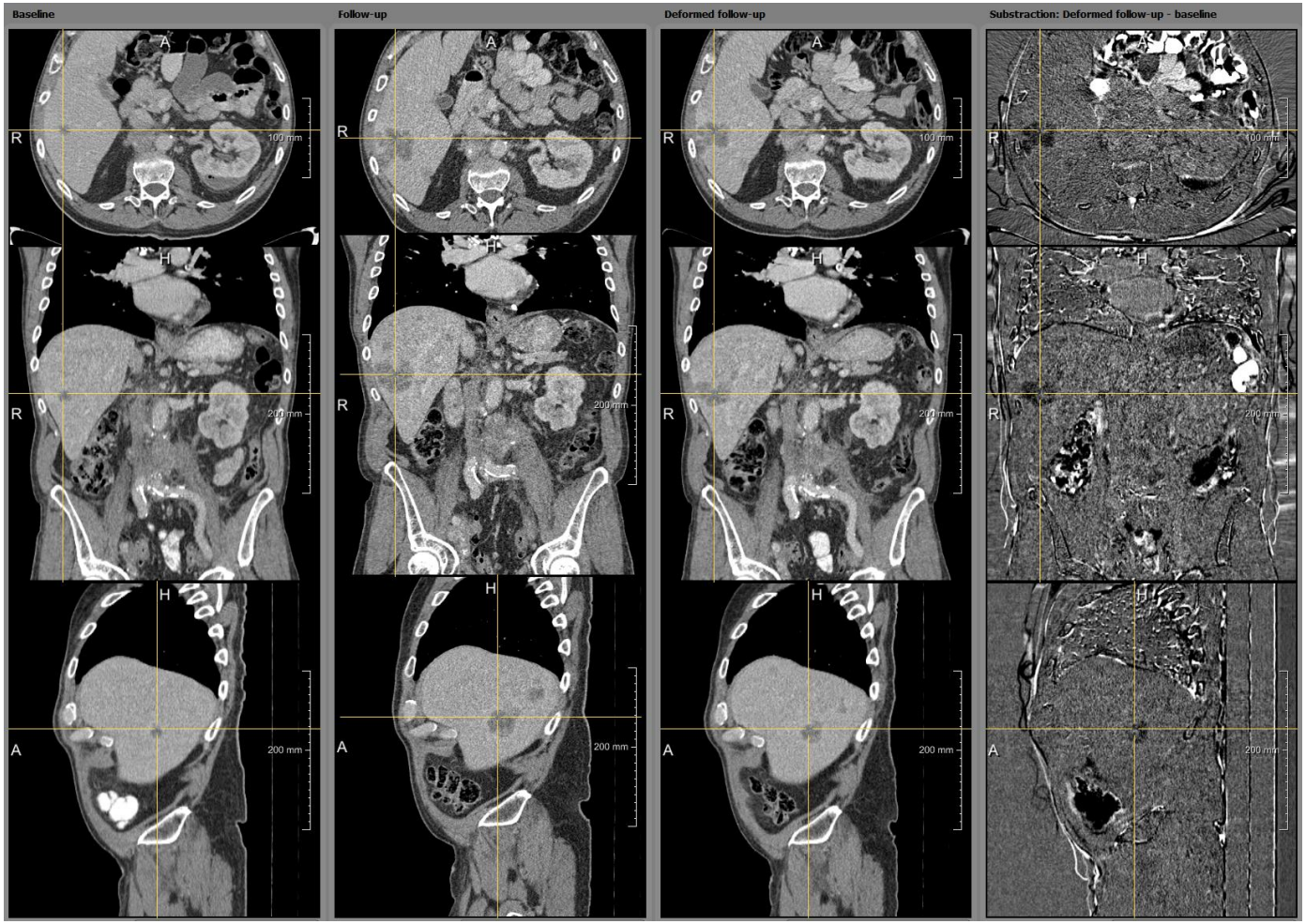
Stefan Heldmann[1]

[1]Fraunhofer Institute for Medical Image Computing MEVIS, Lübeck, Germany, www.mevis.fraunhofer.de

The First International Workshop on

Thoracic Image Analysis @ MICCAI2018 Granada SPAIN

Motivation – a simple example



Baseline follow-up deformed follow-up substraction

Fraunhofer MEVIS

Motivation

- Image registration problem for change assessment:

  Perfect match ↔ Local differences

- State-of-the art:

  Deformable Registration with local rigidity
  (Haber et al. 2009, König et al. 2016, Loeckx et al 2004, …)

  Comparative exploration of bone lesions in MRI (Dzyubachyk et al. 2013)

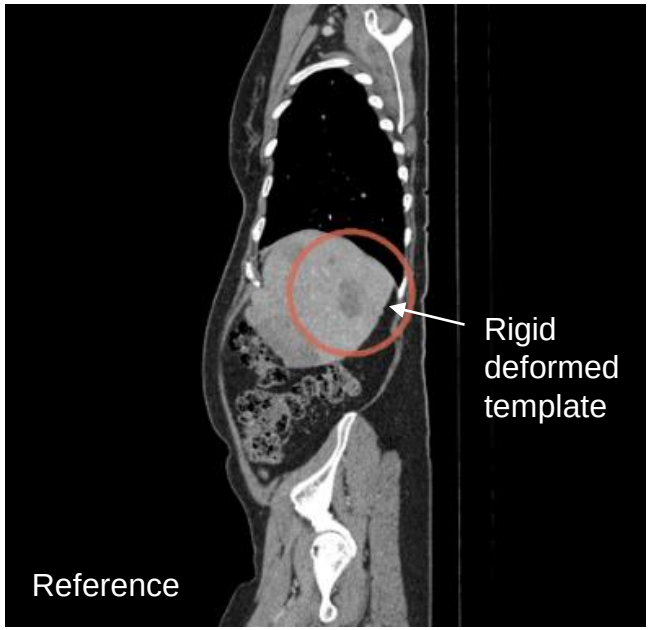
- What we want: a tool for (automatic) change detection and assessment

Method

- Given: baseline scan R, follow-up scan T and deformation vector field y.
- Image registration: Use deformable registration to get deformation y which minimizes image similarity of R and T(y) and regularity of y.

  (Brown 1992, Goshtby 2012, Modersitzki 2004, Modersitzki 2009, Sotiras et al. 2013, …)
- Rigid lens concept:

  Reference image R with lens region L containing rigidly deformed template image T.



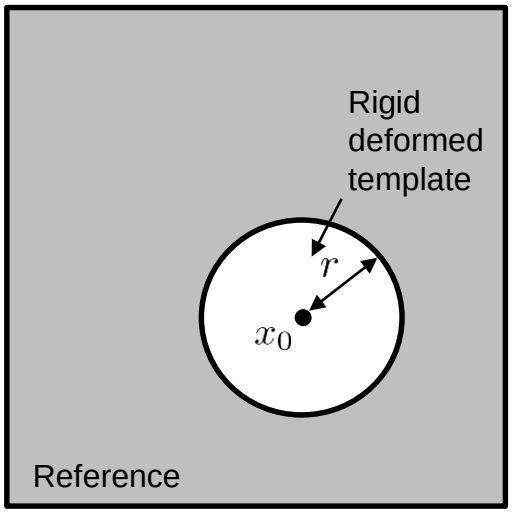
Rigid lens - Mathematical model

Given:

- Images $R, T : \mathbb{R}^3 \to \mathbb{R}$ and deformation $y : \mathbb{R}^3 \to \mathbb{R}^3$
- Lens region $\mathcal{L} \equiv \mathcal{L}_r(x_0) := \{\text{grid point } x \text{ with } \|x - x_0\|_2 \leq r\}$

Goal: Find $y_{\text{rigid}}(x) = Qx + b$ such that

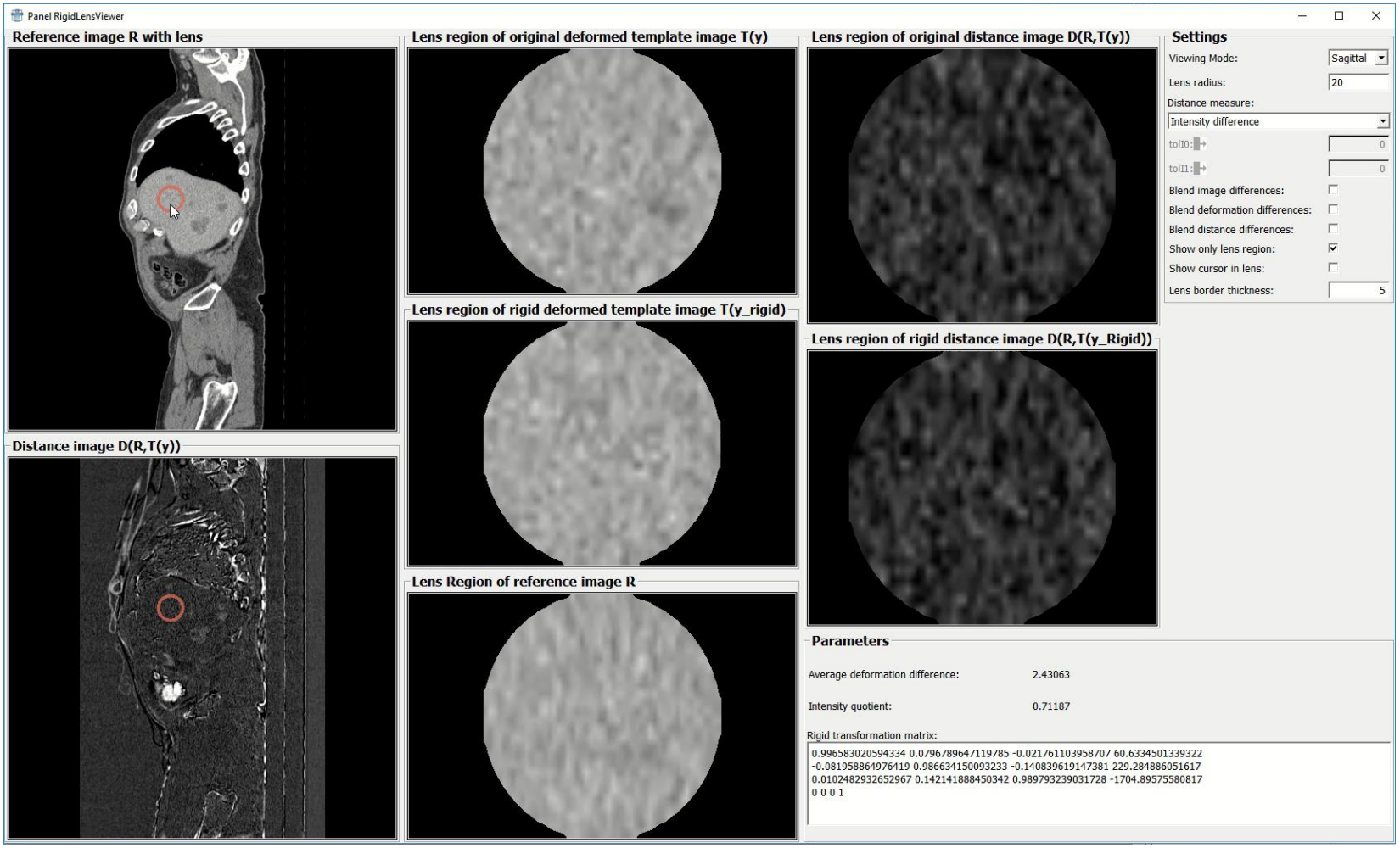
$$\sum_{x \in \mathcal{L}} \|y(x) - y_{\text{rigid}}(x)\|^2 \stackrel{!}{=} \min .$$



Rigid Lens - Algorithm

- Well-known problem, also called Procrustes matching (Whaba 1965):
  Find $y_{\text{rigid}}(x) = Qx + b$ such that $\sum_{x \in \mathcal{L}} \|y(x) - (Qx + b)\|^2 \stackrel{!}{=} \min$
- Solution can be explicitly calculated with various approaches
  (Arun et al. 1987, Horn 1987, Horn et al. 1988, Walker et al. 1991)
- Here we use the algorithm from Arun et al. 1987:
  - based on a singular value decomposition of a 3x3 matrix
  - Numerically most stable method (Eggert et al. 1997)

Rigid Lens – demo video



Rigid Lens measures for automatic change detection

- Measuring the non-rigidity of the deformation:

$$d_{\text{def}} = \frac{1}{|\mathcal{L}|} \sum_{x \in \mathcal{L}} \|y(x) - y_{\text{rigid}}(x)\|$$ (Average deformation difference)

- Measuring the volume change:

$$d_{\text{jac}} = \frac{1}{|\mathcal{L}|} \sum_{x \in \mathcal{L}} \det \nabla y(x)$$ (Average jacobian)

- Measuring the visible changes:

$$d_{\text{int}} = \frac{\sum_{x \in \mathcal{L}} |D(y_{\text{rigid}}, x) - D(y, x)|}{\sum_{x \in \mathcal{L}} D(y_{\text{rigid}}, x)}$$ (Relative intensity difference quotient)

with difference image $D(y, x) := |R(x) - T(y(x))|$

$d_{\text{int}} \approx 0$, if deformation y is already rigid

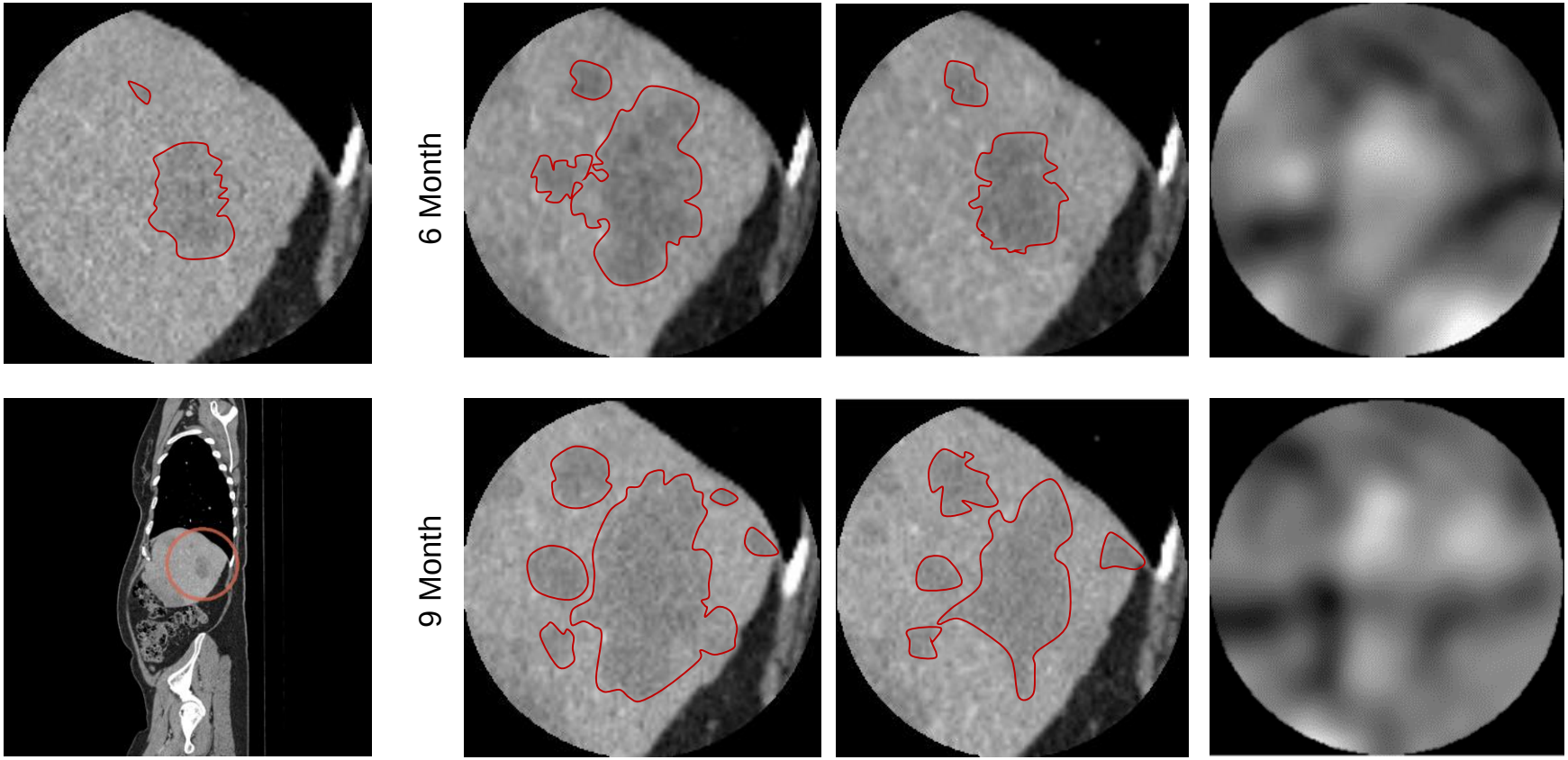
$d_{\text{int}} \approx 1$, if deformation y matches R and T perfectly

Results – qualitative study

Rigid Lens

Lens location

Baseline R | Follow-Up $T(y_{\text{rigid}})$ | $T(y)$ | $||y - y_{\text{rigid}}||$



Fraunhofer MEVIS

Results – qualitative study

Rigid Lens

→ With rigid lens the real change is visible

Rigid Lens measures

Follow-Up	d_{def}	d_{jac}	d_{int}
6 month	2.93	1.02	0.63
9 month	3.81	1.06	0.76

→ The change can be also detected with the rigid lens measures

$$d_{\text{def}} = \frac{1}{|\mathcal{L}|} \sum_{x \in \mathcal{L}} \|y(x) - y_{\text{rigid}}(x)\|, \quad d_{\text{jac}} = \frac{1}{|\mathcal{L}|} \sum_{x \in \mathcal{L}} \det \nabla y(x), \quad d_{\text{int}} = \frac{\sum_{x \in \mathcal{L}} |D(y_{\text{rigid}}, x) - D(y, x)|}{\sum_{x \in \mathcal{L}} D(y_{\text{rigid}}, x)}$$

Results – quantitative study for change detection

- Design:
  - 1263 thorax-abdomen CT scans and 2898 tumor annotations of 487 patients from the oncology department at the Radboud UMC.
  - tumor annotations with a diameter ≥ 2cm
  - Definition of rigid lens region with position and diameter of annotation
- Results:

Tumor Type	Number	d_{def}	d_{jac}	d_{int}
Liver	352	2.88 ± 1.91	1.01 ± 0.34	0.52 ± 0.12
Lung	157	2.65 ± 2.26	1.03 ± 0.33	0.49 ± 0.14
Other	983	3.27 ± 1.98	0.99 ± 0.37	0.55 ± 0.14
All	1492	3.11 ± 2.01	1.00 ± 0.36	0.54 ± 0.14

$$d_{\text{def}} = \frac{1}{|\mathcal{L}|}\sum_{x\in\mathcal{L}} \|y(x) - y_{\text{rigid}}(x)\|, \quad d_{\text{jac}} = \frac{1}{|\mathcal{L}|}\sum_{x\in\mathcal{L}} \det \nabla y(x), \quad d_{\text{int}} = \frac{\sum_{x\in\mathcal{L}} |D(y_{\text{rigid}}, x) - D(y, x)|}{\sum_{x\in\mathcal{L}} D(y_{\text{rigid}}, x)}$$

Results – quantitative study for change detection

- We observe a large range of d_{def} from 0.05mm up to 16.13mm.
- The measured d_{jac} is in average ≈ 1, but the standard deviation is > 30%.
- We measured a high intensity quotients on a significant high level.

  → The rigid lens measures are sensitive to changes

- Results:

Tumor Type	Number	d_{def}	d_{jac}	d_{int}
Liver	352	2.88 ± 1.91	1.01 ± 0.34	0.52 ± 0.12
Lung	157	2.65 ± 2.26	1.03 ± 0.33	0.49 ± 0.14
Other	983	3.27 ± 1.98	0.99 ± 0.37	0.55 ± 0.14
All	1492	3.11 ± 2.01	1.00 ± 0.36	0.54 ± 0.14

$$d_{\text{def}} = \frac{1}{|\mathcal{L}|} \sum_{x \in \mathcal{L}} \|y(x) - y_{\text{rigid}}(x)\|, \quad d_{\text{jac}} = \frac{1}{|\mathcal{L}|} \sum_{x \in \mathcal{L}} \det \nabla y(x), \quad d_{\text{int}} = \frac{\sum_{x \in \mathcal{L}} |D(y_{\text{rigid}}, x) - D(y, x)|}{\sum_{x \in \mathcal{L}} D(y_{\text{rigid}}, x)}$$

CONCLUSION

- Rigid lens - a simple, fast and interactive tool for change detection
- Rigid lens measures
  - features for detecting shape, size and appearance changes
  - sensitive to changes (quantitative study)
- Future work:

  → Extension for automatic change detection

  → Generalization to multi-modal registration