Artifact-Resistant Motion Estimation for Motion-Compensated CT

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Slowly Rotating CBCT Devices

• Image-guided radiation therapy (IGRT)
  – CBCT imaging unit mounted on gantry of a LINAC treatment system
  – E.g. used for patient positioning

• Maximum gantry rotation speed of 6° per second

• Breathing cycle about 2 to 5 seconds
  – i.e. 12 to 30 respirations per minute (rpm) and thus per scan

⇒ Account for respiratory motion!
Retrospective Gating

Without gating (3D): Motion artifacts

With gating (4D): Sparse-view artifacts
Prior Art in IGRT
(Respiratory-Correlated Reconstructions)

• Respiratory gating and independent reconstruction
  – Sparse-view artifacts deteriorate image quality
    » Streak artifacts and image noise
  – Increased patient dose required

• Dedicated acquisition techniques
  – These are not accepted in clinical routine, e.g., due to long acquisition times
  – Increased patient dose required

• Conventional motion-compensated reconstruction
  – Necessary motion estimation requires
    » Increased patient dose
    » Additional knowledge, e.g. planning CT
Aim

- Provide high quality respiratory-correlated 4D volumes from on-board CBCT scans
  - Image quality comparable to that of motionless regions (e.g. neck)
- Do this with a standard acquisition protocol
- Do this without other prior information of higher temporal sampling such as a 4D planning CT
  - Account for inter-fractional variations in breathing motion

Results of recent publications from other groups on that topic

Motion Compensation (MoCo)

- Use all projection data for each phase to be reconstructed
  - Even those of other phase bins (100 % dose usage)
  - Compensate for motion using motion vector fields (MVF)
  - In our case MVFs are estimated from gated reconstructions

- Use MVFs during reconstruction
  - Backproject sparse data along straight lines, then warp with respect to the MVFs
A Standard Motion Estimation and Compensation Approach (sMoCo)

- Motion estimation via standard 3D-3D registration
- Has to be repeated for each reconstructed phase
- Streak artifacts from gated reconstructions propagate into sMoCo results

A Cyclic Motion Estimation and Compensation Approach (cMoCo)

- Motion estimation only between adjacent phases
  - All other MVFs given by concatenation

- Incorporate additional knowledge
  - A priori knowledge of quasi periodic breathing pattern
  - Non-cyclic motion is penalized
  - Error propagation due to concatenation is reduced

Displacement curve of a fictitious pixel over complete respiratory cycle

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Angular Sampling Artifact Model

- Create second series of images with sparse-view artifacts but without breathing motion
- Eliminate breathing motion information
  - Threshold-based segmentation of 3D CBCT
- Simulate measurement and reconstruction process
  - Forward projection of segmented image
  - Backprojection at same angles as for gated 4D CBCT

\[ C = -200 \text{ HU}, \ W = 1400 \text{ HU} \]
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Motion Estimation using an Patient-Specific Artifact Model

Simulate Motionless Projection Data

Measured Data

3D CBCT

Segmented Image

Forward Projections

Gating and Independent Reconstruction

Gated 4D CBCT

4D Artifact Images

Cyclic Registration

Motion Vector Fields (induced by breathing and artifacts)

Motion Vector Fields (Corrected)

Motion Vector Fields (induced by artifacts only)

acMoCo: Artifact Model-Based Motion Compensation
Patient Data – Results

3D CBCT
Standard

Gated 4D CBCT
Conventional
Phase-Correlated

sMoCo
Standard Motion
Compensation

acMoCo
Artifact Model-Based
Motion Compensation

C = -200 HU, W = 1400 HU
Summary

• Severe sparse-view artifacts deteriorate image quality of conventional phase-correlated images.
• Standard deformable 3D-3D registration is sensitive to these artifacts.
• Highly decreased sensitivity to sparse-view artifacts by combination of cyclic registration and artifact model.
• Motion-compensated image reconstruction using MVFs obtained by combination of cyclic registration and artifact model appears to be suitable for application in IGRT.
Thank You!

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This presentation will soon be available at www.dkfz.de/ct.

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