Medical Image Processing for Interventional Applications

Data Consistency

Online Course – Unit 34

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Pattern Recognition Lab (CS 5)

Topics

Motion Compensation

Data Consistency Conditions

Summary

Take Home Messages

Further Readings

Motion Compensation

- Result in reconstruction artifacts in the final images: **motion blur**
- Degraded image quality lowers **diagnostic confidence.**
- **Effects increase** with acquisition time.

Figure 1: Motion-free

Figure 2: Motion-corrupted

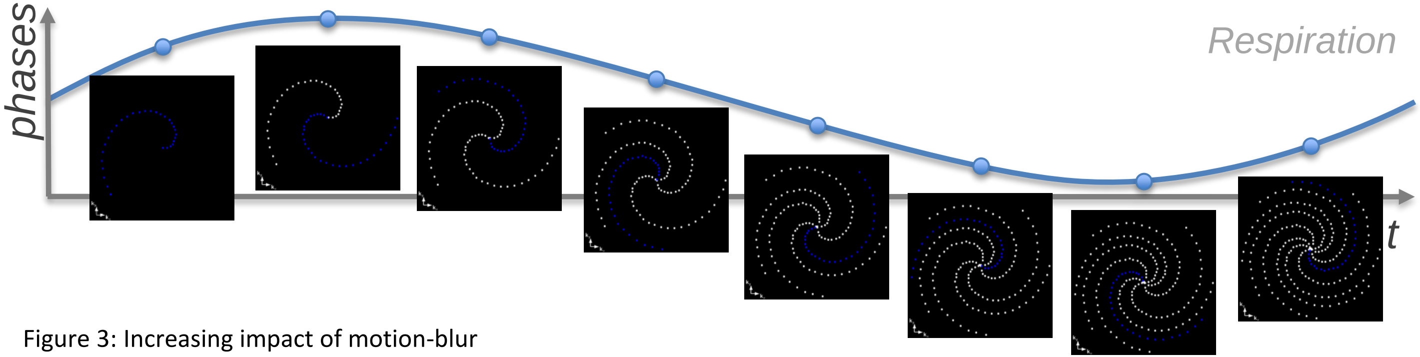
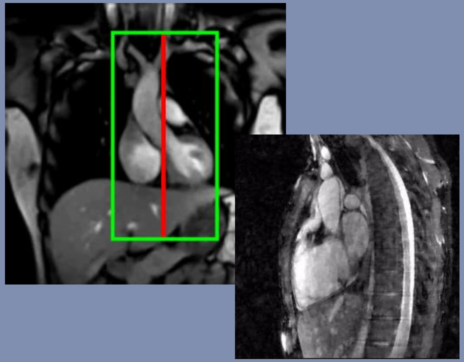
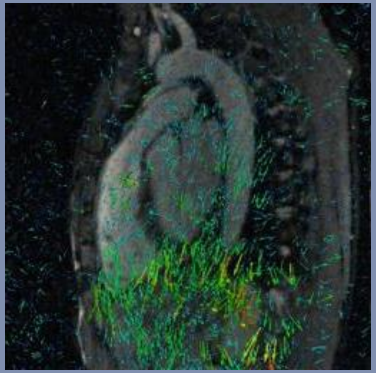


Figure 3: Increasing impact of motion-blur

Motion Compensated Reconstruction



Motion-Detection



Motion-Compensation

Reconstruction

- **Initial reconstruction** of individual respiratory phases with **weighted compressed sensing** reconstruction.
- **Image registration** to estimate the **displacement** due to respiratory motion.
- Apply **displacement field** on acquired data.
- Reconstruction of the resulting **motion-compensated** data.

Motion Compensated Reconstruction: Resulting Images

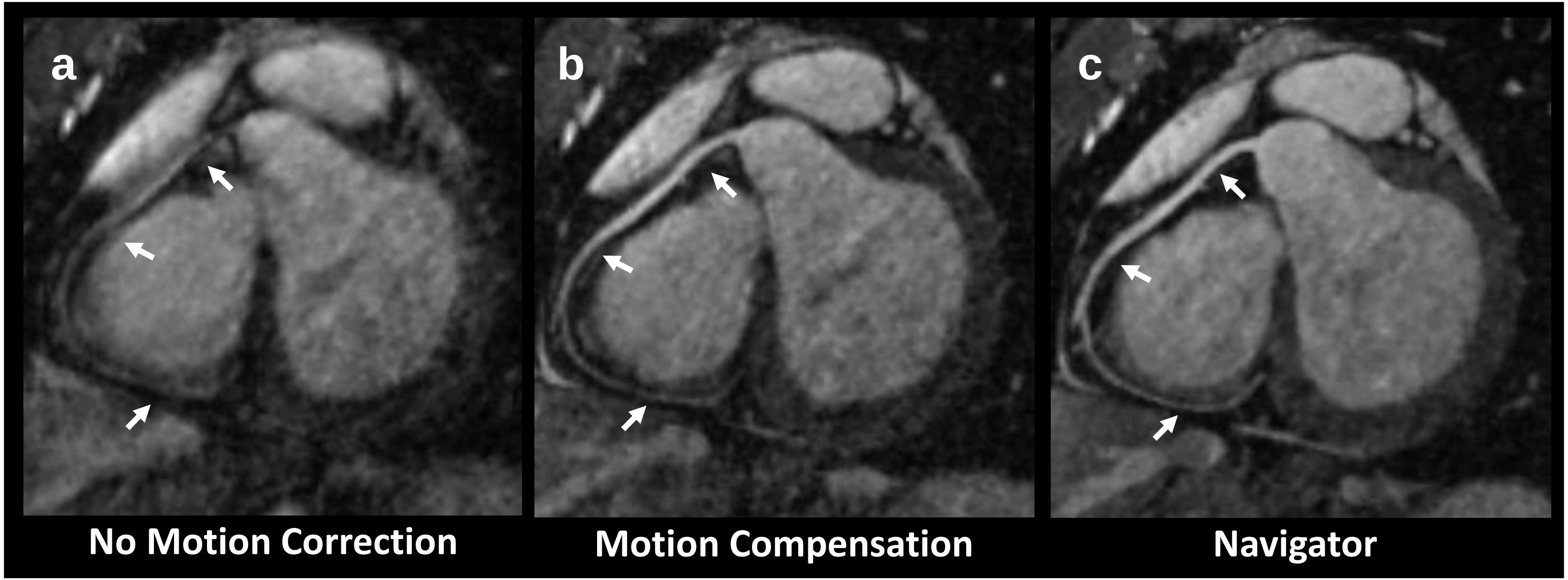


Figure 7: Reformatted images showing the right coronary artery (RCA) reconstructed (a) without any correction and (b) using motion compensation. (c) An additional navigator-gated scan is performed for reference.

Motion Compensation

Standard FDK reconstruction | ECG-gated reconstruction | PICCS + iTV reference reconstruction | Result of CMHPR algorithm

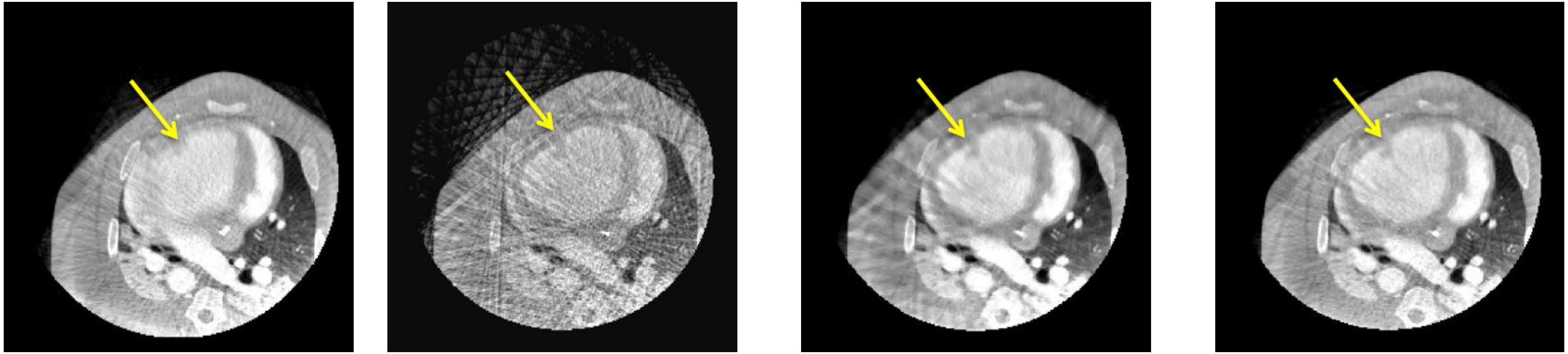


Figure 8: Experimental results in porcine model p1 of the central slice and a relative heart phase of 80 %. (W 1630 HU, C 50 HU, slice thickness 1.0 mm). The ECG-gated reconstruction was windowed to be visually comparable (images courtesy of Kerstin Müller, Pattern Recognition Lab, FAU).

Bulk Rigid Motion / Online Calibration

- Scanner-related:
  - Imperfect system geometry (C-Arm wobble)
  - Outdated calibration
- Patient-related:
  - Patients suffering from stroke (rigid head motion)
  - Slight tremor while standing (rigid case)

→ Motion model with few parameters

→ Interventional application requires fast computation.

Data Consistency Metrics

Goal:

- Describe consistency that is inherent to a CT acquisition.
- Allow the correction of sources of "inconsistency": motion, scatter, truncation.

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- Purely image-based
  → No additional sensors
- Before/without reconstruction
  → Fast

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Cons:

- Works only for certain applications/geometries
- Many results from simulations published (since over 25 years)
- Few real data results published
- Never applied in real systems

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Data Consistency Conditions

Parallel beam conditions:

- Projection moments (Helgason & Ludwig, 1985)
- Sinogram Fourier space (Natterer & Edholm, 1986)

Extensions:

- Moments:
  - Fan beam (Clackdoyle)
  - Cone beam (Clackdoyle & Desbat)
- Fourier Space:
  - Fan beam (Mazin & Pelc)
  - Cone beam (Brokish & Bresler)

Moments (Parallel)

$$\int_0^{2\pi} \left(\int_{-\infty}^{\infty} s^m p(s, \Theta) ds \right) e^{-ik\Theta} d\Theta = 0$$

$$\forall k, m \in \mathbb{N} \quad \wedge \quad k > m \geq 0$$

Moments (Parallel)

m-th order moment of the projection

$$\int_0^{2\pi} \left(\boxed{\int_{-\infty}^{\infty} s^m p(s,\Theta) ds} \right) e^{-ik\Theta} d\Theta = 0$$

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k-th order Fourier expansion

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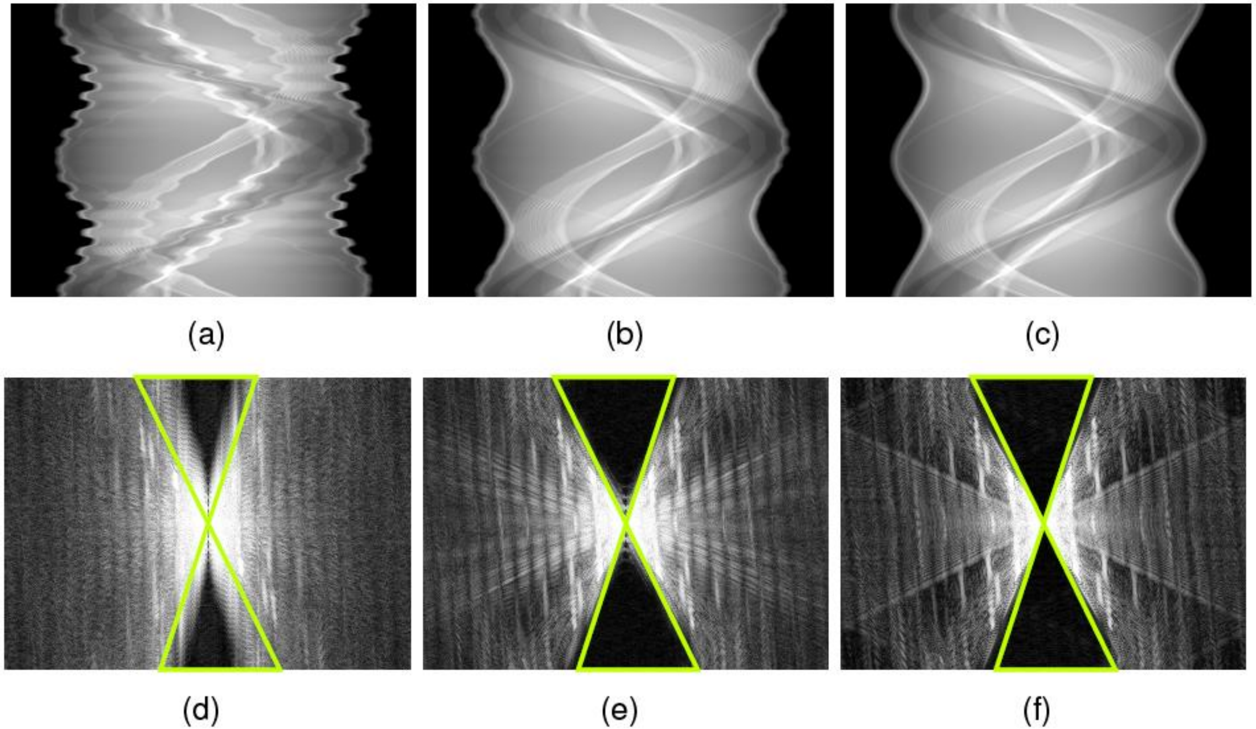
Example (*m=0*)

- Inner integral becomes the total mass of the projection.
- Outer integral constrains all frequencies (*k>m*) to 0.

⇒ Total mass is identical in all projections.

Sinogram Fourier Space



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- In image processing algorithms that depend on multiple acquisitions like image reconstruction, motion creates artifacts in uncompensated images.
- Motion compensation is a broad research topic, but approaches using data consistency are rather scarce and mostly deal with simulated data only.
- In the following units we look deeper into data consistency and epipolar geometry.

Further Readings

André Aichert et al. "Epipolar Consistency in Transmission Imaging". In: *IEEE Transactions on Medical Imaging* 34.11 (Nov. 2015), pp. 2205–2219. DOI: 10.1109/TMI.2015.2426417

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