A Robust Fully Automatic Method for Intrinsic Respiratory and Cardiac Gating for Cone-Beam CT Scans of the Thorax Region

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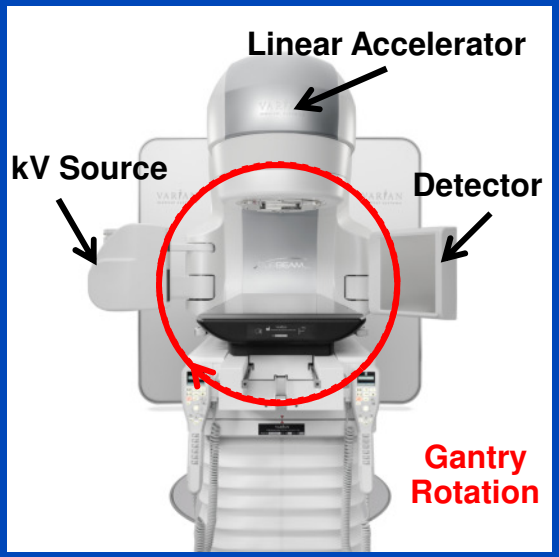
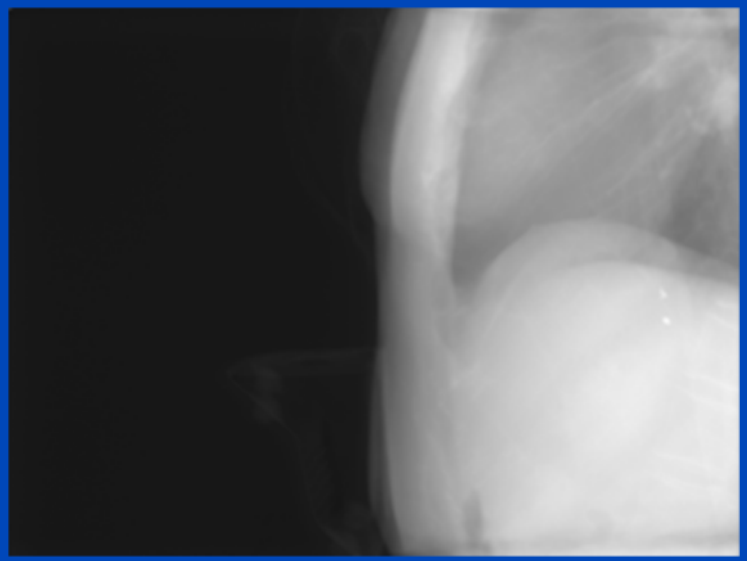
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

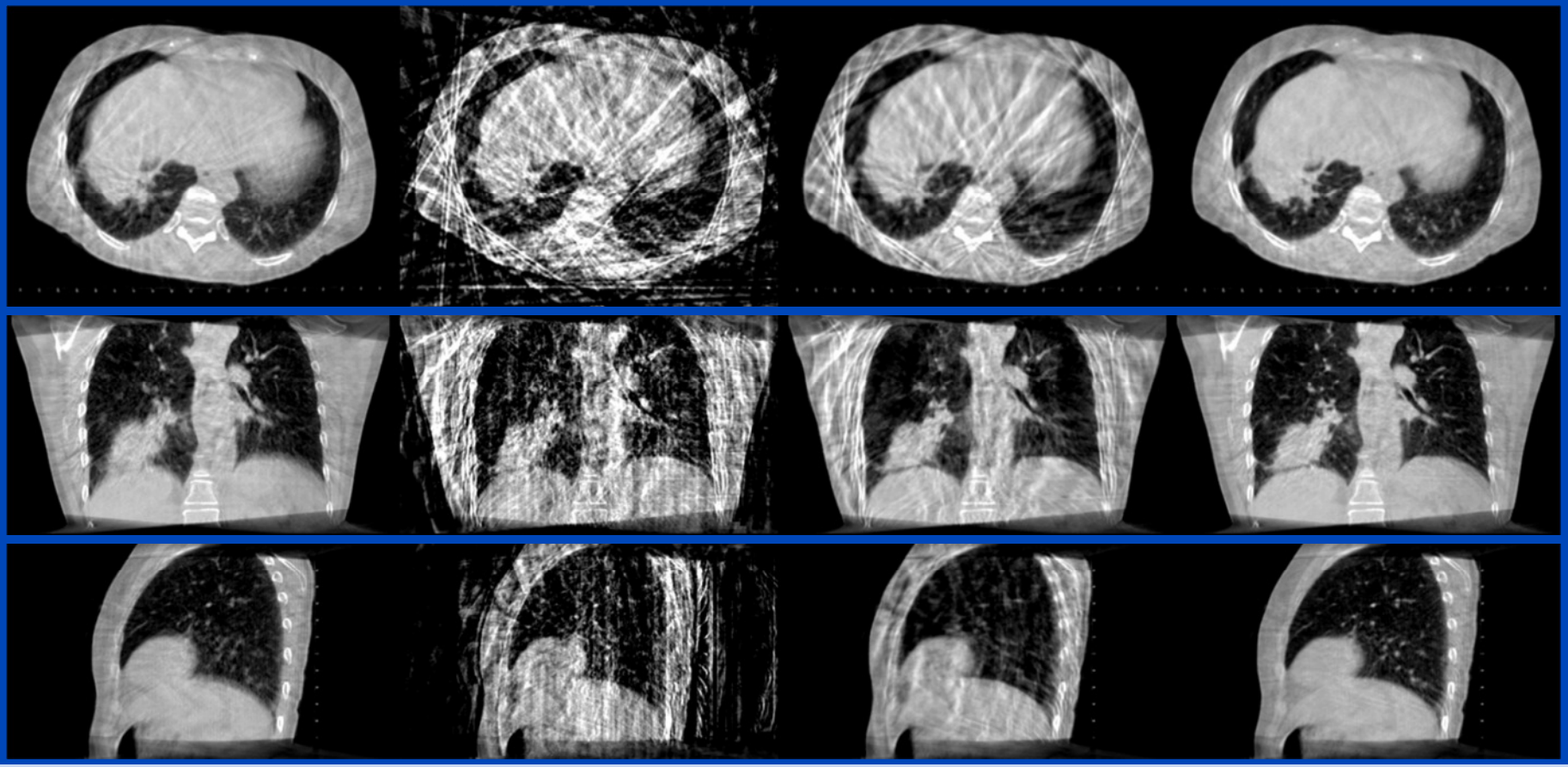
Aim

- Provide intrinsic respiratory and cardiac gating signals (peaks) for scans
  - where no external signal is available
  - or where the gating signal is corrupted
- Do not require any user input





Patient Example where a Gating Signal is Required



varian

Brehm, Paysan, Oelhafen, and Kachelrieß, "Artifact-resistant motion estimation with a patient-specific artifact model for motion-compensated cone-beam CT" Med. Phys. 40(10):101913, 2013.

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External Respiratory/Cardiac Signal Acquisition

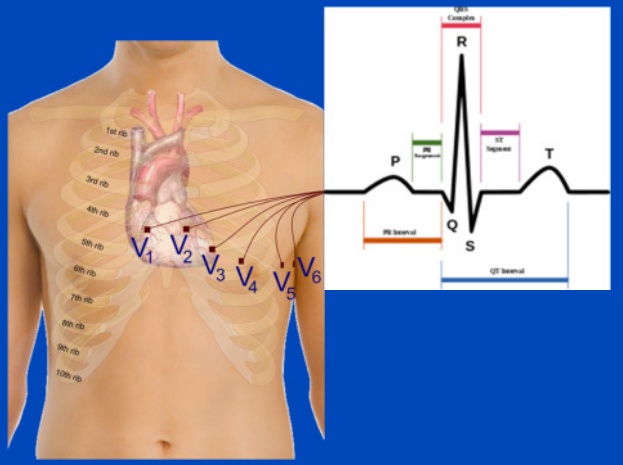
RPM system

Image property of VARIAN medical images

Respiration Belt

Image property of AKTINA MEDICAL

ECG



Pulse Oximeter

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Intrinsic CT Gating Prior Art

	Method	Respiratory Gating	Cardiac Gating	Fully Automatic	CBCT
[1]	Kymogram detection	X	✓	✓	X
[2-6]	Resp. gating	✓	X	✓	✓
[7-9]	Small animal CT: Resp. gating	✓	X	X	✓
[10,11]	Small animal CT: Resp. + card. Gating	✓	✓	✓ X	✓
	Proposed algorithm	✓	✓	✓	✓

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[2] L. Zijp et al. *Extraction of the Respiratory Signal from Sequential Thorax Cone-Beam x-ray Images*, Int. Conf. on the Use of Computers in Radiation Therapy, pp 507–9, 2004
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[10] J. Dinkel et al. *Intrinsic gating for small-animal computed tomography: a robust ECG-less paradigm for deriving cardiac phase information and functional imaging*, Circ Cardiovasc Imaging 1(3):235-43, Nov 2008
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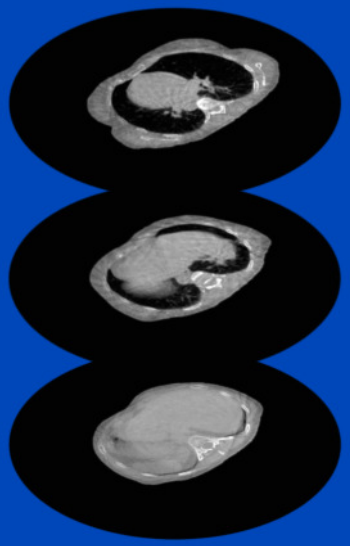
Respiratory Gating



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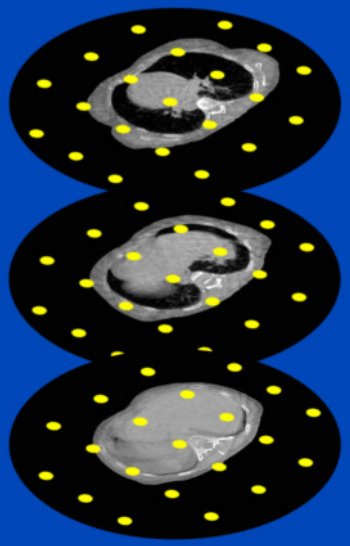
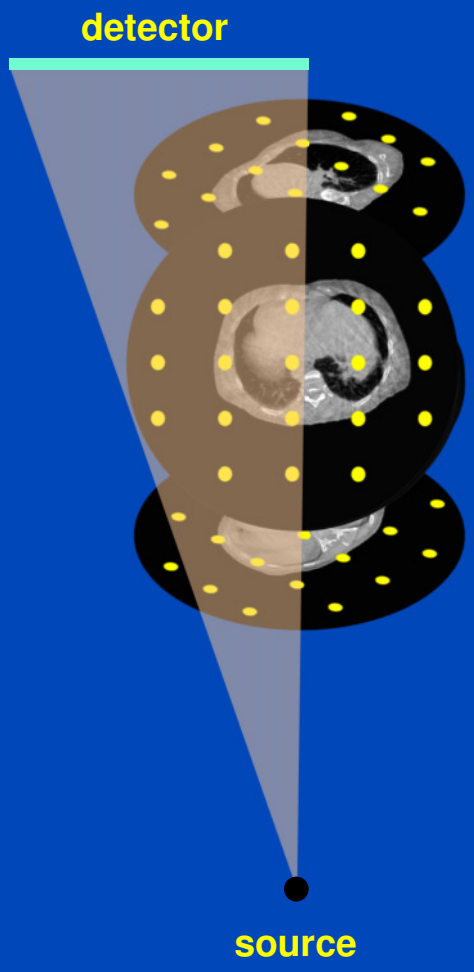
Respiratory Gating

- Grid points are distributed regularly in the volume.



Respiratory Gating



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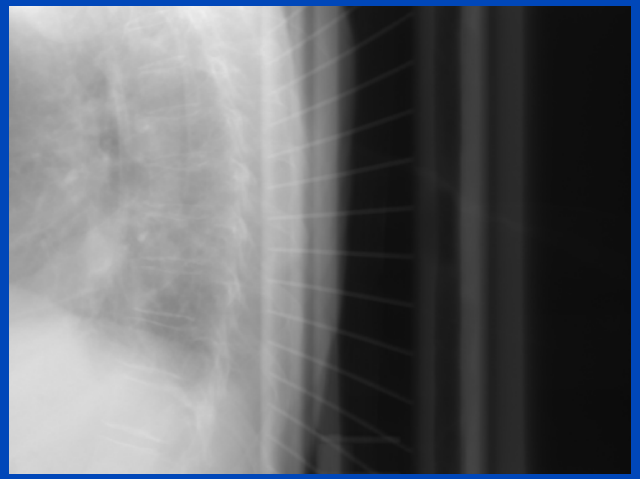
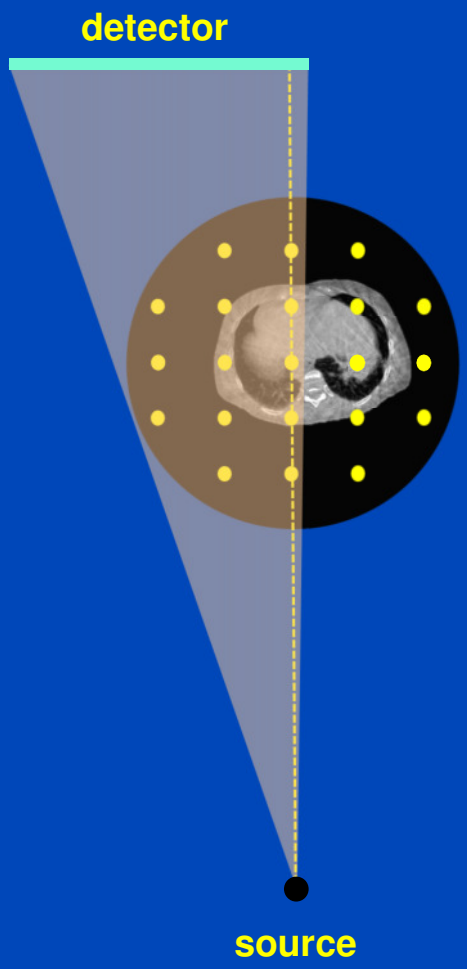
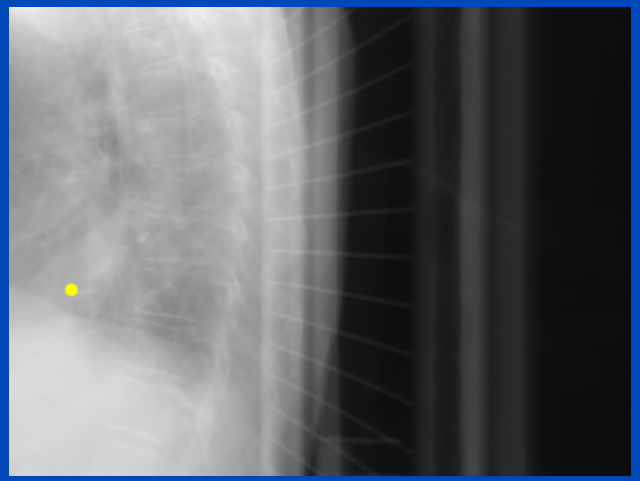


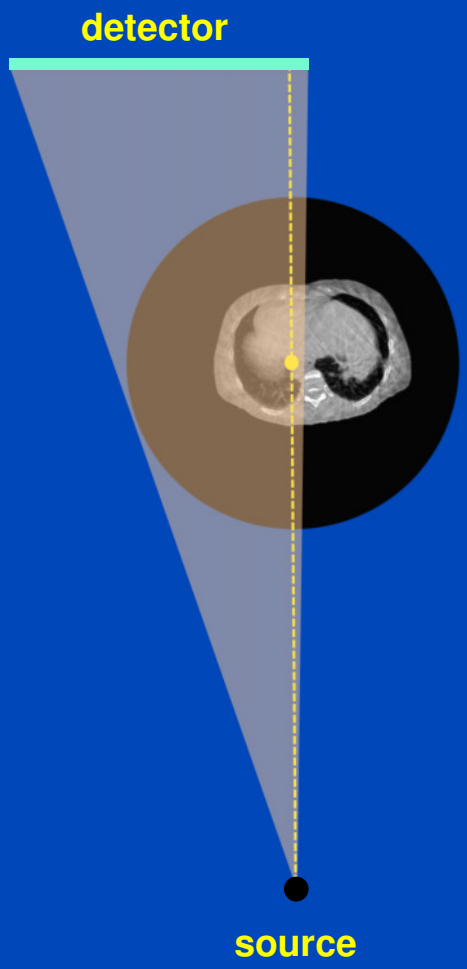
Respiratory Gating



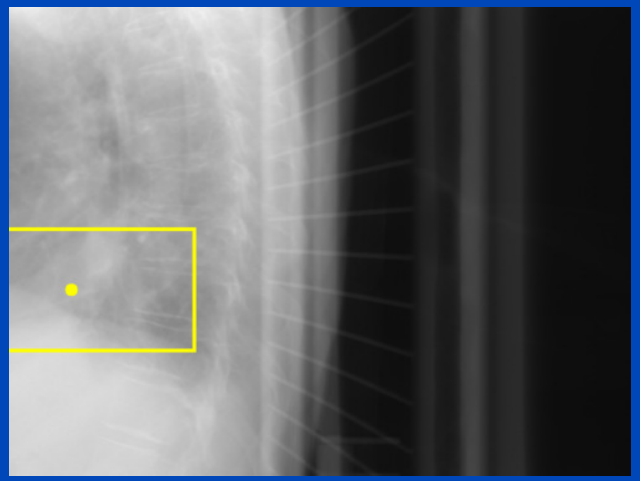
- Grid points are distributed regularly in the volume.
- Each grid point is
  - tracked on the detector



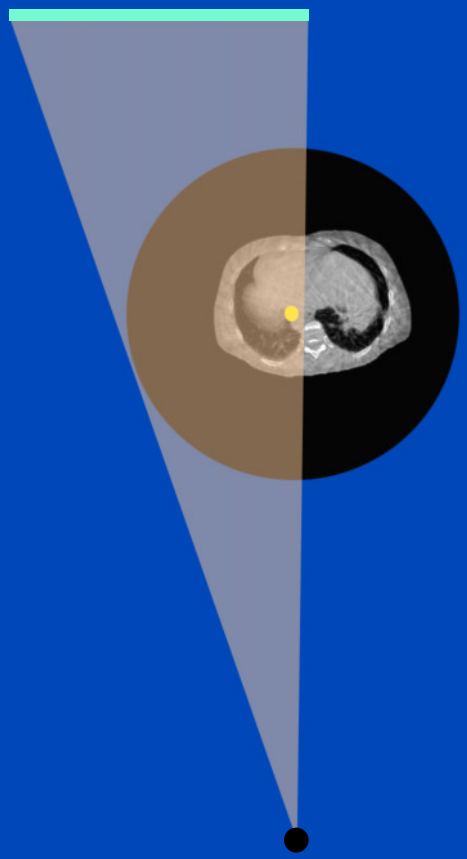
Respiratory Gating



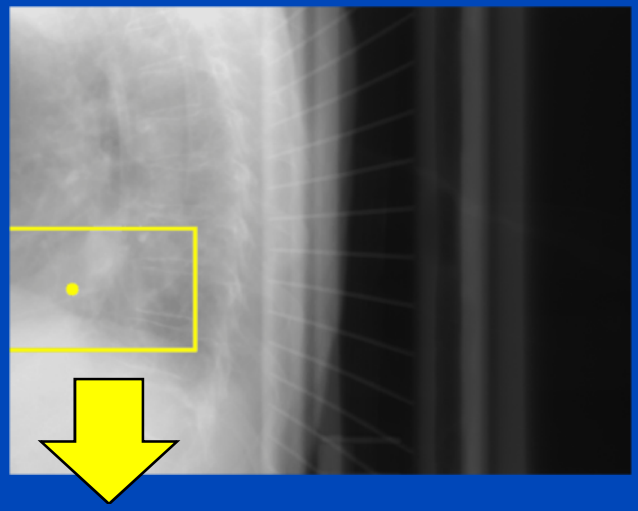
- Grid points are distributed regularly in the volume.
- Each grid point is
  - tracked on the detector
  - center of a rectangular ROI in the projections

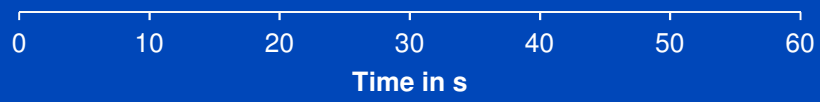


Respiratory Gating

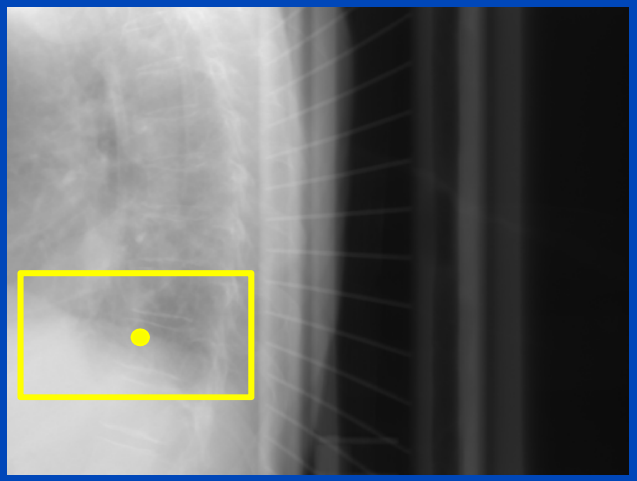


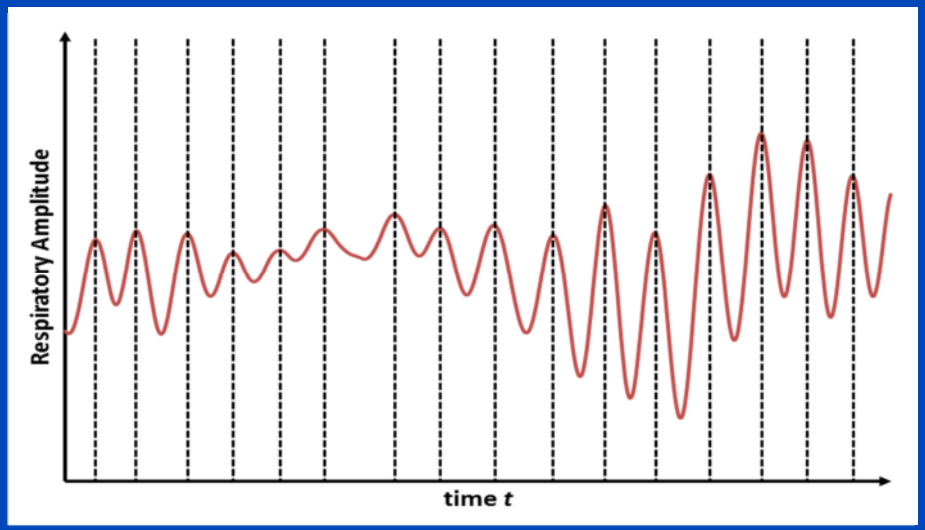
- Mean gray value + band-pass filter as motion surrogate
- Determine peaks automatically by finding local maxima
- Result: Signal with most regular peaks





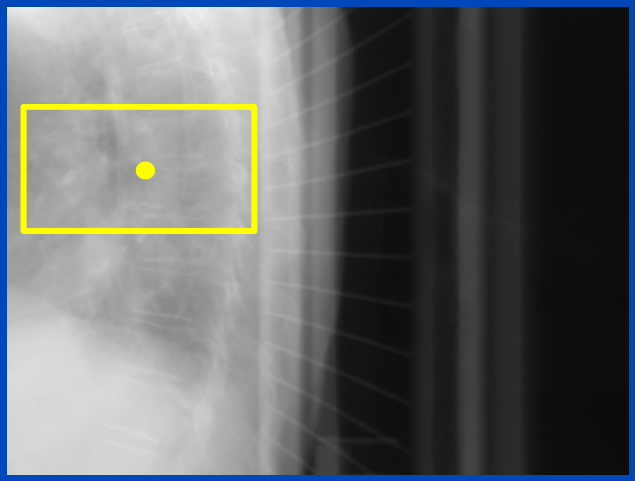
Good ROI

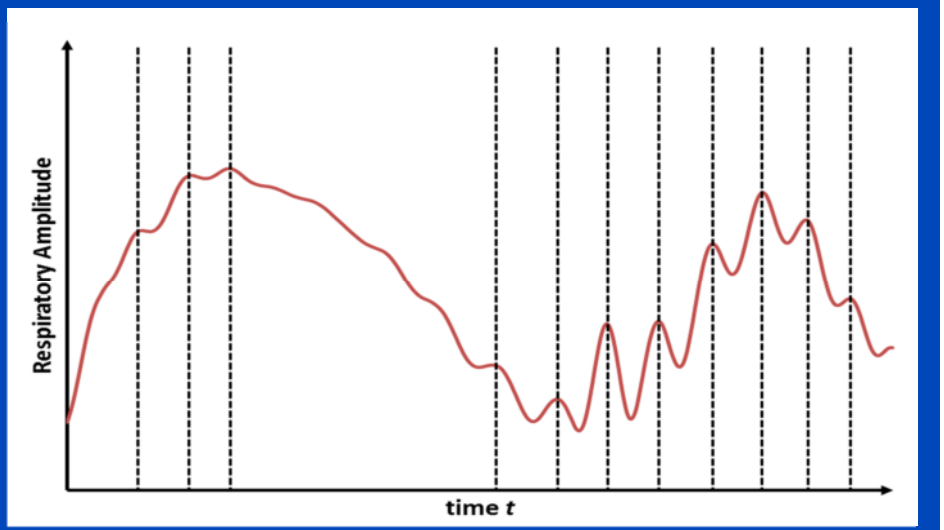




very regular peaks

Bad ROI





irregular peaks

Select the ROI with the most regular peaks!

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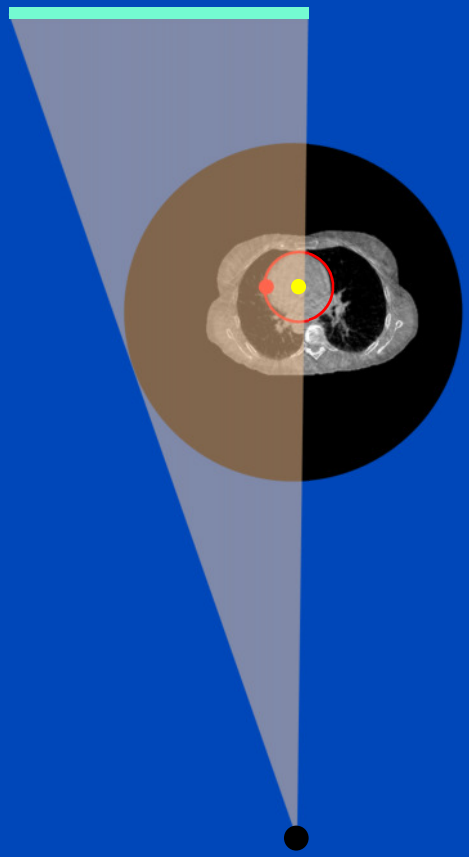
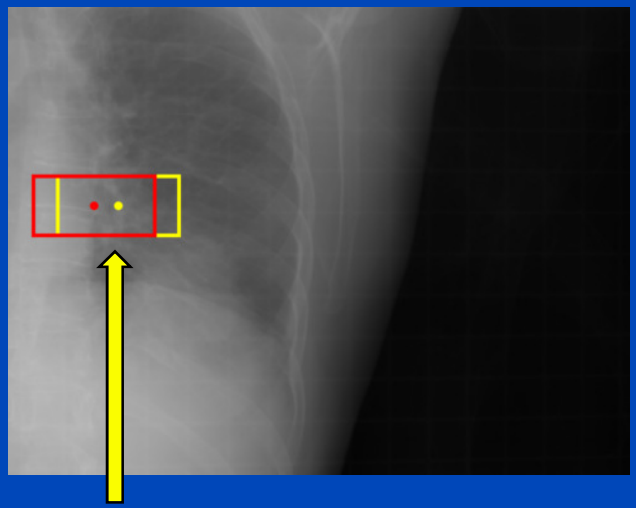
Cardiac Gating

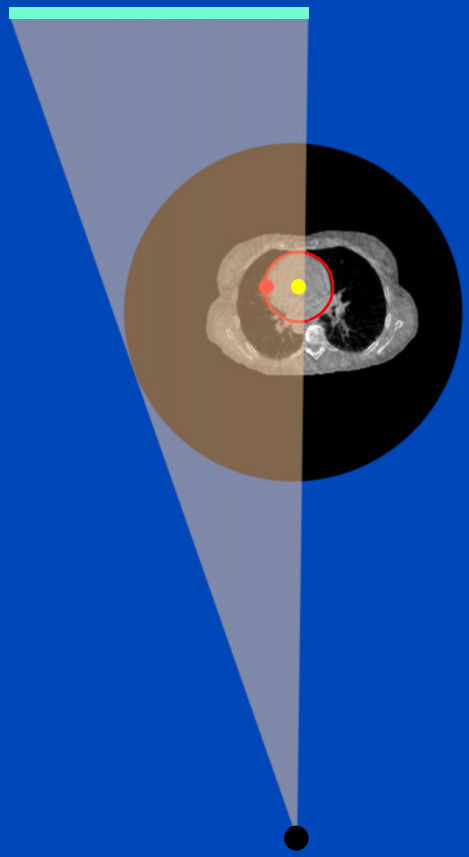


Cardiac gating:
Surface of circle around grid point is tracked.

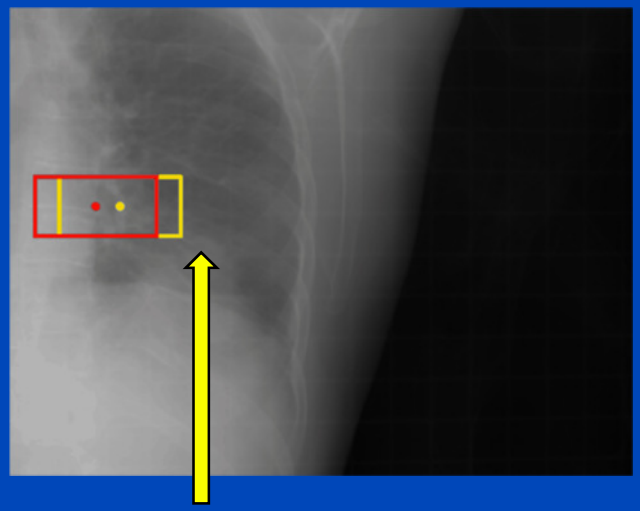


Ventricular wall is covered by <u>both</u> ROIs.

Cardiac Gating



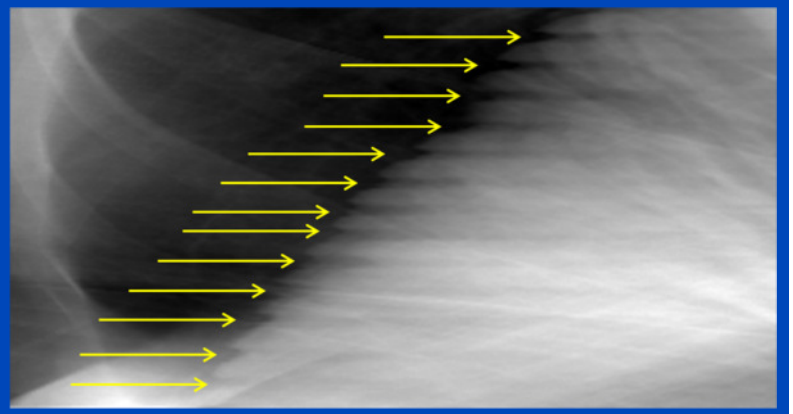
Cardiac gating:
Surface of circle around grid point is tracked.



Ventricular wall is only covered by this ROI!

Evaluation

- 10 patients
- 60 s scan time
- Respiratory gating:
  - Grid: 20 × 20 × 20
  - ROI size: about 12 by 8 cm
  - Band-pass: 10 to 30 rpm
  - GT: Varian RPM system
- Cardiac gating:
  - Grid: 50 × 50 × 50
  - ROI size: about 8 by 4 cm
  - Band-pass: 50 to 120 bpm
  - Radii: 30 mm to 50 mm in steps of 2 mm
  - GT: Manual evaluation of sinogram



Results

Respiratory Gating

Patient	RPM_{GT}	RPM_{IG}	ΔRPM
1	19	19	0
2	26	26	0
3	20	20	0
4	11	11	0
5	11	11	0
6	9	9	0
7	23	23	0
8	23	23	0
9	26	26	0
10	23	23	0

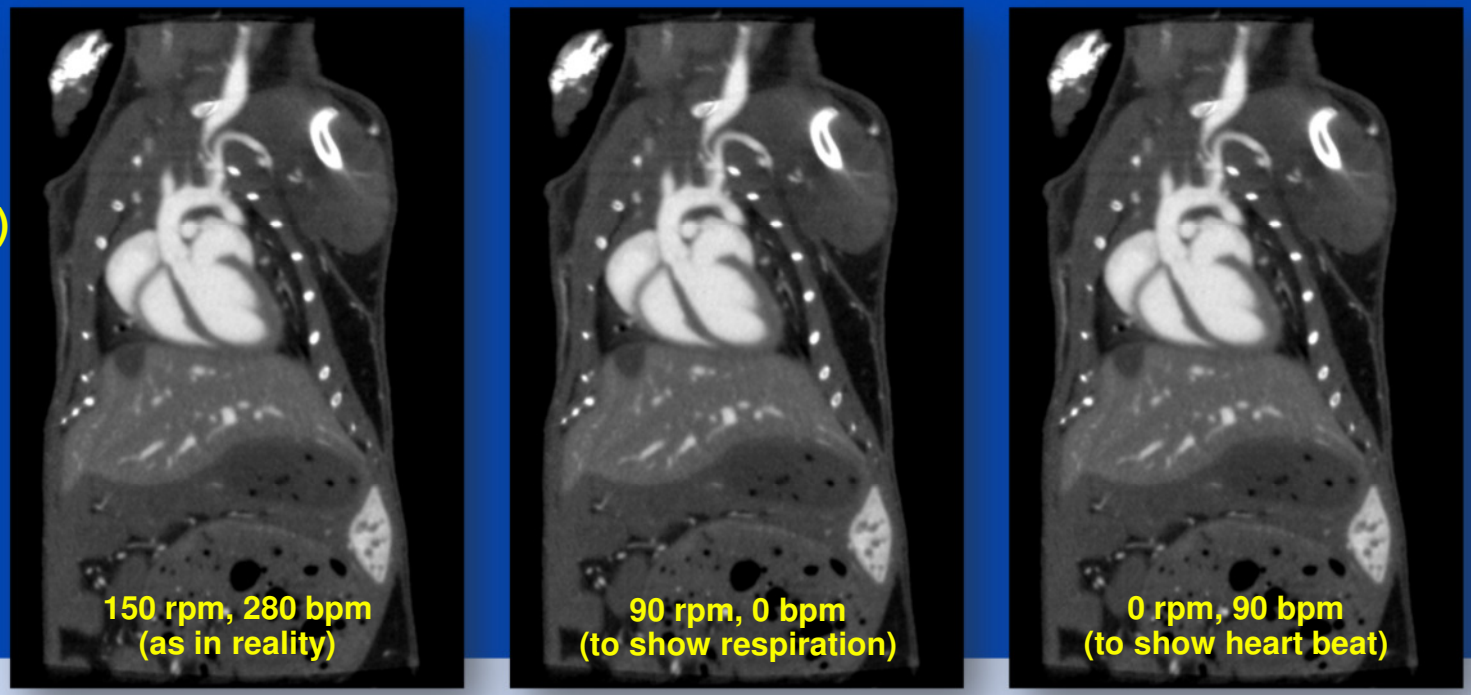
Cardiac Gating

Patient	BPM_{GT}	BPM_{IG}	ΔBPM
1	80	80	0
2	70	69	-1
3	65	66	1
4	70	70	0
5	52	52	0
6	61	61	0
7	78	78	0
8	69	70	1
9	86	86	0
10	74	74	0

Conclusions

- Our method determined the correct respiratory peaks for all patients with a maximum error of 522 ms in the position of the maximum.
- Our method correctly determined the cardiac peaks in 7 patients. The remaining 3 patients showed a maximum error of 1 peak.

5D micro-CT mouse example (5D MoCo[1])



[1]Brehm, Sawall, Maier, and Kachelrieß, Med. Phys. 42(4):1948-1958, 2015.

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Thank You!

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