

Motion Artifacts and Suppression in MRI At a Glance

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MRI Motion Artifacts and Suppression At a Glance Outline



- Background Physics
- Common Motion Suppression/Reduction Methods
- Advanced Non-Cartesian Methods

Overview Motion Magnitude



Alexander AL et al., Neurotherapeutics 2007;4:316-329.
 Harauz G et al., J Nucl Med 1979;20:733-735.

Weiss PH et al., J Nucl Med 1972;13:758-759.
 Axel L, AJR 1984;143:1157-1166.

Overview Common Motions in MRI

Typical motion categories*

- Diffusion
- Macroscopic motion
- Fluid flow

Incoherent motion \rightarrow amplitude attenuation \rightarrow Useful information to measure

Coherent motion → Useful information to measure → Image artifact source



Source: http://en.wikipedia.org/wiki/Brownian_motion







* Merboldt K et al., Magn Reson Med 1989;9:423-429.

Overview k-space, MR Images and Cartesian Imaging



Overview Effects Caused by Motion in MRI

Intra		
	Inter-view Effect	Intra-view Effect
Motion duration	Between the views, i.e. phase encoding steps	Within the view (mainly during signal readout)
Typical artifacts	 Image blurring Complete or incomplete replica of the moving tissue, i.e. ghosts 	 Image blurring Increased image noise
Typical motion type	Periodic motion	Random movement

1. Mitchell DG et al., MRI Principles 2004;416.

2. Hedley M et al., Mag Reson Imaging 1992;10:627-635.

Overview Common Motion Types and Effects

Macroscopic motion

- Physiological motion
 - Respiratory motion: Mainly inter-view effects
 - Cardiac motion: Both inter- and intra-view effects
- Gross movement (voluntary or involuntary): Both inter- and intra-view effects
 - Head/limb movement/rotation during long scan
 - Pediatric or elderly patients who cannot hold their breath
 - Uncooperative subjects

Fluid flow

- Fast velocity: Primarily an intra-view effect
- The pulsation: Inter-view effects

1. Mitchell DG et al., MRI Principles 2004;416.

2. Hedley M et al., Mag Reson Imaging 1992;10:627-635.

Cartesian Imaging Motion Artifacts

- Cartesian Imaging and Fourier Transform
 - Phase encoding lines differ by constant phase offset $\Delta \phi$

 - Motion \rightarrow Additional phase \rightarrow "Displacement of lines"
 - Violation of Nyquist theorem (local) → Ghosting artifacts

Known facts¹⁻²

- Motion leads to ghosting in the PE direction -> Can be used to displace artifacts
- The motion direction is irrelevant



1. Schultz CL et al., Radiology 1984;152:117-121. 2. Ehman RL et al., Radiology 1986;159:777-782.

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Cartesian Imaging Separation of Motion Ghosting

$$Y_{G} = \frac{Y_{tot} \times n_{av} \times TR}{T}$$

- Y_G: The number of pixels between two consecutive ghosts
- Y_{tot}: The total number of pixels across the FOV
- n_{av}: The number of averages of each phase encoding step
- TR: The repetition time
- T: The period of motion



Wood ML et al., AJR1988;150:513-522.

Cartesian Imaging Pulsation Motion Artifacts



Courtesy of Martinos Center for Biomedical Engineering, MGH/Harvard John Kirsch, PhD Siemens Healthcare, Boston, MA, USA

Motion Suppression

Common Methods to Suppress Motion Artifacts

No monitoring

- Breath-holding (with the help of accelerated imaging methods)
- Averaging of data

Monitoring

- Cardiac gating
- Navigator gating
- Respiratory gating

Respiratory Motion Compensation – No Monitoring Breath-holding

- Breath-hold: Still the most efficient and easiest way to suppress motion
- In practice, long acquisition time can be very challenging for breathholding



25 sec breath-hold (Respiratory motion at the end)

Respiratory Motion Compensation – No Monitoring Accelerated Imaging: Leaving Out k-space Data Points

- Parallel imaging methods
 - SENSE¹
 - GRAPPA²
 - CAIPIRINHA³
 - etc

- Highly undersampled/sparse-sampled k-space
 - Compressed sensing⁴



- Pruessmann AL et al., Mag Reson Med 1999;42:952-962.
 Breuer FA et al., Mag Reson Med 2006;55:549-556.
- 2. Griswold MA et al., Mag Reson Med 2002;47:1202-1210.
 4. Lustig M et al., Mag Reson Med 2007;58:1182-1195.

Respiratory Motion Compensation – No Monitoring Breath-holding

Accelerated imaging methods make the breath-hold easier to accomplish







25 sec breath-hold (Respiratory motion at the end) 7 sec breath-hold CAIPIRINHA Acceleration factor 4 5 sec breath-hold CAIPIRINHA Acceleration factor 5

Respiratory Motion Compensation – No Monitoring Averaging of Data

- Multiple signal measurements during free breathing do not directly correct motion artifacts
- However, averaging multiple measurements works, because
 - Signal of an object varies less than that of motion artifacts, and is added coherently
 - Intensity of ghosts is decreased due to destructive interference between measurements
- Other benefit: SNR increase -> by a factor of $\sqrt{N_A}$
- Drawback: longer scan time

1. Wood ML et al., AJR1988;150:513-522.

2. Chavhan GB et al., RadioGraphics 2013;33:703-719.

Motion Compensation – Monitoring Cardiac Gating

ECG gating: A standard way for cardiac imaging, especially for cine imaging



- Peripheral pulse gating
 - Cannot be used for cardiac imaging due to the long and unpredictable delay between cardiac contraction and arrival of the pulse wave to the finger.
 - Good for peripheral MRA and for cine CSF flow studies

Motion Compensation – Monitoring Navigator Gating



Motion Compensation – Monitoring Navigator Gating



No navigator gating

With navigator gating

Courtesy of Martinos Center for Biomedical Engineering, MGH/Harvard John Kirsch, PhD Siemens Healthcare, Boston, MA, USA

Motion Compensation – Monitoring Respiratory Gating

- Respiratory motion can be detected by a thoracic/abdomen belt, bellows or cushion
 - It does not disrupt the imaging and are independent of field strength
 - It actually measures the abdominal wall motion, not the diaphragm
 - But generally correlates with diaphragm motion very well*



Santelli C et al., Mag Reson Med 2011;65:1097-1102.

From Cartesian to Non-Cartesian K-space Trajectory and Reconstruction

Cartesian trajectory

- Radial trajectory
 - Regridding
 - Radial k-space -> Cartesian k-space





 Finally, Fourier Transfer the regridded Cartesian k-space to images

Radial Imaging Advantages

Radial: Varying readout directions

- Components shifted in different directions
- Signal blurring instead of shift
- Off-resonance correction can help deblur

Advantages

- Insensitive to motion and flow artifacts
- Can be acquired with free breathing



Pediatric Patient Imaging Example 1 9-year-old patient with tuberous sclerosis



Cartesian

Radial

Courtesy of Tobias Block, PhD NYU Langone Medical Center, New York, NY, USA Christian Geppert, PhD Siemens Healthcare, New York, NY, USA

Pediatric Patient Imaging Example 2

4-week-old patient with port-wine stain (suspected Sturge-Weber)



One Step Further from Radial Imaging **BLADE/PROPELLER**

- PROPELLER (Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction) (GE: PROPELLER, Siemens: BLADE, Philips: MultiVane)
 - An hybrid trajectory of radial and cartesian
 - Using rotating blades with multiple phase-encoding lines
 - k-space center is oversampled to
 - Correct in-plane rotation and translation
 - Reject data based on estimates of through-plane motion
 - Further decrease motion through averaging

Known facts

- Can correct rigid motion/rotation
- Can correct respiratory motion

Pipe JG, Magn Reson Med 1999;42:963-969.

Head Example Brain Pulsation Motion



Cartesian

BLADE

Courtesy of Martinos Center for Biomedical Engineering, MGH/Harvard John Kirsch, PhD Siemens Healthcare, Boston, MA, USA

Abdomen Example Respiratory Motion





Regular TSE

BLADE TSE

Courtesy of Martinos Center for Biomedical Engineering, MGH/Harvard John Kirsch, PhD Siemens Healthcare, Boston, MA, USA

Summary

- Motion can be useful information, but is often the source of image artifacts
 - Motion can cause inter- and intra-view effects, leading to motion artifacts
 - Motion typically causes ghosts in the phase encoding direction, and image blur
- The commonly used motion suppression and reduction methods include
 - Non-monitoring methods, such as breath-hold and multiple averaging
 - Monitoring methods, such as cardiac/respiratory/navigator gating
- The non-Cartesian imaging methods are emerging promising methods for motion suppression
 - Radial imaging
 - PROPELLER / BLADE / MultiVane



Thank you for your attention!