ISMRM Motion Correction Workshop

Motion correction in MRI, a vendor's perspective

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Summary

- Motion is one of the main sources of artefacts MRI scans. It may lead to blurring and ghosting
- To cope with this, you can try to **avoid** the motion, to **adapt** to the motion or try correct for it
- Correcting motion can be subdivided in **detecting** motion and how or when to **apply** the correction

Introduction

In a photo camera the shutter speed can be used to freeze fast-moving subjects. When the shutter speed is too slow, blurring of moving objects occurs. Some other means the photographer has to correct for motion are instructing the object to stand still, pan the camera to track the motion or use some kind of image stabilization method to correct for camera motion. While the shutter speed of a camera typically ranges from 1 ms to 1 second, the scan time in an Magnetic Resonance Imaging (MRI) scan usually starts at 1 second and can range up to several minutes. The long scan times are probably the biggest enemy. But since MRI is looking *inside* the body, we are also dealing with specific sources of motion like swallowing, respiration, the beating heart and peristalsis. Each of these sources may need a different approach. Most motion compensation techniques require special examination parameters to describe how the motion is detected and how to apply the correction. A selection of current motion compensation techniques available in state-of-the-art MRI scanners and how they affect the scan protocol are described below.

Avoiding motion

The best way to correct for motion in MRI is to simply avoid the motion. This can start with reducing anxiety and claustrophobia by dedicated lighting and video projection to calm down patients. Furthermore, immobilization and careful instructing the patient will help to create the right starting point for a motion free MRI scan.

Avoiding motion is similar to adjusting the shutter speed and means to adjust the scan time to expected motion. Respiratory artefacts can be avoided by acquiring the scans during breath hold. This may impact the scan protocol and therefore it is needed to specify it explicitly. Longer scans can be subdivided in several breath holds to end up with short enough breath holds. Alternatively, the resolution can be automatically adjusted based on the breath hold duration as parameter. During the scan, the scanner can provide feedback on the scan progress to the operator and patient (1).

In periodic motion it is often useful to distinguish the quiet phase and use this to acquire the data. This can be done using triggering; i.e. only scan at a certain interval. Or by using gating; i.e. scan continuously and discard all data outside the quiet phase. In both cases the acquisition is divided in shots with a duration that matches the quiet phase and the acquisition may be timed with a trigger or gate delay. In cardiac synchronized scans, mid-diastole is often identified as the quiet part of the scan (2). Further fine-tuning is possible by observing the varying duration of the cardiac cycle and based on that, adapt the optimal trigger delay (3).

Adapting to motion

Sampling data in the presence of periodic motion can lead to distinct ghosting artefacts. Averaging data in scans is used to weigh out incoherent motion artefacts. Averaging can be done on the short term meaning acquiring the same data in subsequent repetition times (“parallel averaging”). But to correct for motion, we want to separate the averages as far as possible: acquire all data first and then repeat the scan again for the second and subsequent average (“serial averaging”). When the MRI data is acquired in Turbo methods, the k-space is divided in segments. This gives the opportunity to randomize the shot order to scramble the periodic motion and reduce motion artefacts. Both methods are relative simple optimizations of adapting the acquisition order to the motion and are fully determined before the acquisition. Amore sophisticated method is to map the periodic motion to the k-space (4). The effect is that motion manifests itself in blurring. This requires a real-time estimate of the motion and a decision on which profile to be measured.

Detecting motion

For most motion compensation techniques, a prerequisite is to be able to measure the motion. Traditionally this is done using external sensors such as peripheral pulse units, VCG electrodes or respiratory bellows. Another common method is to use a dedicated MRI sequence like a navigator (5). Navigators can for example be a 1D, pencil beam shaped excitation through the diaphragm to measure respiratory cycle. It can also be phase navigator in DTI scans that measure motion during diffusion gradients.

Recently the MR data itself is used to detect the motion, this is known as self-gating (6). A major advantage of incorporating respiratory “navigators” into the acquisition is that no additional pencil-beam pulses are necessary, which reduces the planning effort and improves the ease-of-use. Selfnavigation can be extended to use the startup cycles in a turbo field echo scan to acquire a 2D image navigator (7) but it also has its limitations; it cannot easily be applied to any sequence.

Interleaving of 2D (8, 12) and even 3D image navigators (9) is becoming a new challenge for vendors who are usually interested in robust motion detectors that can generally be applied. The navigator sequences were originally embedded in the pulse sequence itself and only available to a limited number of scan techniques. Also, modifications to the navigator were limited. Embedding navigators in scan protocols cause maintenance problems and architectural complications. Therefore, a new framework was developed that allows interleaving multiple, completely independent MRI scan in a seamless way (10). Switch points between the scans are usually before a turbo shot or before a dynamic but can be set at any time and there is zero overhead in switch time. One obvious application is to embed short motion detection scans into other scans. All scans are also reconstructed in parallel and the results of the motion detection scan can be used the other scans.

Applying motion correction

Motion estimation during the scan is good for several reasons. It can be used to reject certain data if an algorithm decides the data is too far off. It can also be used to correct the data and to optimize the data acquisition scheme. And it may be used to feedback to the patient and operator. Feedback may be given in a fun way by representing the breathing pattern in a game (11) to encourage the patient to long periods of inhaling and exhaling with short transitional periods.

Prospective motion correction uses information on the motion to change the data acquisition in real time in such a way that it follows the object. The idea is to image in the “Patient Frame of Reference” and not in the “Magnet Frame of Reference”. One major advantage of prospective correction is the ability to correct for through-plane motion and it can be even extended to affine corrections (13). Another advantage is that it not only adjusts the excitation volume of the image itself but also of prepulses that may influence the contrast. And next to updating the excitation volume it is sometimes also beneficial to update the timing of contrast pulses, especially in arrhythmic patients (14). The processing of the data takes usually place on the spectrometer itself and may introduce some latency in applying the correction. On the other hand, the analysis of an entire fMRI volume can reveal a geometry update that can be applied prospectively to the next dynamic scan

Retrospective motion correction tries to reduce the effects of motion after the data have been acquired during reconstruction. Advantages of retrospective corrections include no latency between measuring and applying data and sophisticated reconstruction techniques like PROPELLER (15) and COCOA (16).

REFERENCES

1. Liu YL, Riederer SJ, Rossman PJ, Grimm RC, Debbins JP, Ehman RL. A monitoring, feedback, and triggering system for reproducible breath-hold MR imaging. Magn Reson Med. 1993 Oct;30(4):507-11.
2. Weber OM, Martin AJ, Higgins CB. Whole-heart steady-state free precession coronary artery magnetic resonance angiography.Magn Reson Med. 2003 Dec;50(6):1223-8.
3. Roes SD, Korosoglou G, Schär M, Westenberg JJ, van Osch MJ, de Roos A, Stuber M. Correction for heart rate variability during 3D whole heart MR coronary angiography. J Magn Reson Imaging. 2008 May;27(5):1046-53. doi: 10.1002/jmri.21361.
4. Bailes DR, Gilderdale DJ, Bydder GM, Collins AG, Firmin DN. Respiratory ordered phase encoding (ROPE): a method for reducing respiratory motion artefacts in MR imaging. J Comput Assist Tomogr. 1985 Jul-Aug;9(4):835-8.
5. Ehman RL, Felmlee JP. Adaptive technique for high-definition MR imaging of moving structures. Radiology. 1989 Oct;173(1):255-63.
6. Stehning C, Börnert P, Nehrke K, Eggers H, Stuber M. Free-breathing whole-heart coronary MRA with 3D radial SSFP and self-navigated image reconstruction. Magn Reson Med. 2005 Aug;54(2):476-80
7. Henningsson M, Koken P, Stehning C, Razavi R, Prieto C, Botnar RM. Whole-heart coronary MR angiography with 2D self-navigated image reconstruction. Magn Reson Med. 2012 Feb;67(2):437-45. doi: 10.1002/mrm.23027. Epub 2011 Jun 7.
8. Henningsson M, Smink J, Razavi R, Botnar RM. Prospective respiratory motion correction for coronary MR angiography using a 2D image navigator. Magn Reson Med. 2013 Feb;69(2):486-94. doi: 10.1002/mrm.24280. Epub 2012 Apr 23
9. Moghari MH, Roujol S, Henningsson M, Kissinger KV, Annese D, Nezafat R, Manning WJ, Geva T, Powell AJ. Three-dimensional heart locator for whole-heart coronary magnetic resonance angiography. Magn Reson Med. 2014 Jun;71(6):2118-26. doi: 10.1002/mrm.24881. Epub 2013 Jul 22.
10. Henningsson M, Mens G, Koken P, Smink J, Botnar RM. A new framework for interleaved scanning in cardiovascular MR: Application to image-based respiratory motion correction in coronary MR angiography. Magn Reson Med. 2014 Mar 17. doi: 10.1002/mrm.25149. [Epub ahead of print]
11. Douglas L, Claesson R-M, Ehnmark B, Finnbogason T, Lång R-M, Nordell B, Bruvold M, Smink J, Jhooti P. Using respiratory biofeedback games in pediatric MRI examinations to increase patient comfort and facilitate scanning – a pilot study. ISMRM 2010
12. White N, Roddey C, Shankaranarayanan A, Han E, Rettmann D, Santos J, Kuperman J, Dale A. PROMO: Real-time prospective motion correction in MRI using image-based tracking. Magn Reson Med. 2010 Jan;63(1):91-105. doi: 10.1002/mrm.22176
13. Nehrke K, Börnert P. Prospective correction of affine motion for arbitrary MR sequences on a clinical scanner. Magn Reson Med. 2005 Nov;54(5):1130-8
14. Krishnamurthy R, Pednekar A, Smink J, Cheong B, Muthupillai R, Arrhythmia insensitive inversion recovery preparation (IR-prep) with real-time adaptive inversion delay (TI):phantom validation Journal of Cardiovascular Magnetic Resonance 2010, 12(Suppl 1):P168 doi:10.1186/1532-429X-12-S1-P168
15. Pipe JG. Motion correction with PROPELLER MRI: application to head motion and free-breathing cardiac imaging. Magn Reson Med. 1999 Nov;42(5):963-9
16. Huang F, Lin W, Börnert P, Li Y, Reykowski A. Data convolution and combination operation (COCOA) for motion ghost artifacts reduction. Magn Reson Med. 2010 Jul;64(1):157-66. doi: 10.1002/mrm.22358.