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No Space Navigators

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HIGHLIGHTS

1. No-space navigators, i.e. non-encoded free induction decay navigators, use the fact that the MR FID signal changes when an object is moved with respect to a coil element. They can be sampled very fast and virtually without time penalty.
2. Those signal changes can be used to monitor, i.e. detect motion. The detection can trigger a prospective correction module using a regular MR-based navigator.
3. Recent work shows that FIDnav signal changes contain enough information to back-calculate rigid-body motion parameters.
4. Main limitations/challengers: separate signal changes due to motion from technical and physiological effects plus the restriction to rigid-body bulk motion.

PROBLEM SUMMARY

MR motion navigators sample a portion of data frequently over the course of an MR measurement to derive information about occurred motion. Various motion navigators have been developed in the last decades; most of them, however, bear the disadvantage that the navigator sampling has an impact on the sequence timing, typically prolonging the scan.

Recently, no space or free induction decay navigators (FIDnavs) have been proposed for motion detection and correction [1,2,3]. They monitor the non-encoded (i.e. without applying gradients) FID signals of multi-channel coils during an imaging acquisition. Due to their speed – they can be sampled in some tenths of microseconds (see [1]) – they are compatible with a great variety of imaging sequences with only negligible timing penalty. However, the uncoded signal has no spatial information in the sense of spatially encoded MR signals. This raises several questions:

- How do FIDnavs behave if the image object moves in a (multi-channel) coil?
- Can the FIDnav signal changes be used to detect motion sensitively?
- Contain the signal changes enough information to even quantify the motion?

These questions should be briefly discussed here and in more detail during the related talk on no-space navigators at the ISMRM motion correction workshop in Tromsø in July 2014 (Session 2).

THE PRINCIPLE OF FID NAVIGATORS

Local coil arrays have become essential components of a modern clinical MRI scanner. Due to the steep spatial sensitivity profile of their coil elements, the received signal magnitude and phase change significantly when the object's position is varied with respect to the coil elements. This behaviour is the basis of no-space navigator methods: motion is detected by monitoring the signal changes in the FID of a fixed FOV, which is sampled frequently during a scan. The rationale is hence that the FID is supposed to be invariable throughout the scan and occurring signal changes are due to a changed spatial position of the object with respect to the coil. The helmet design of most modern RF head coils ensures close coverage of the subject's head and hence favours the detection of head motion as outlined above.

For a single-coil-element, the relationship between distance and signal strength can be calculated by means of the electromagnetic laws. In a realistic *in-vivo* experiment, however, various complicating factors, as different loading conditions, head geometry, coil coupling and others, render an analytical approach unfeasible. One can, however, find heuristics which allow for reliably *detection* of motion [2,3 and next section] and even techniques to extract rigid-body motion parameters from the signal changes [4,5].

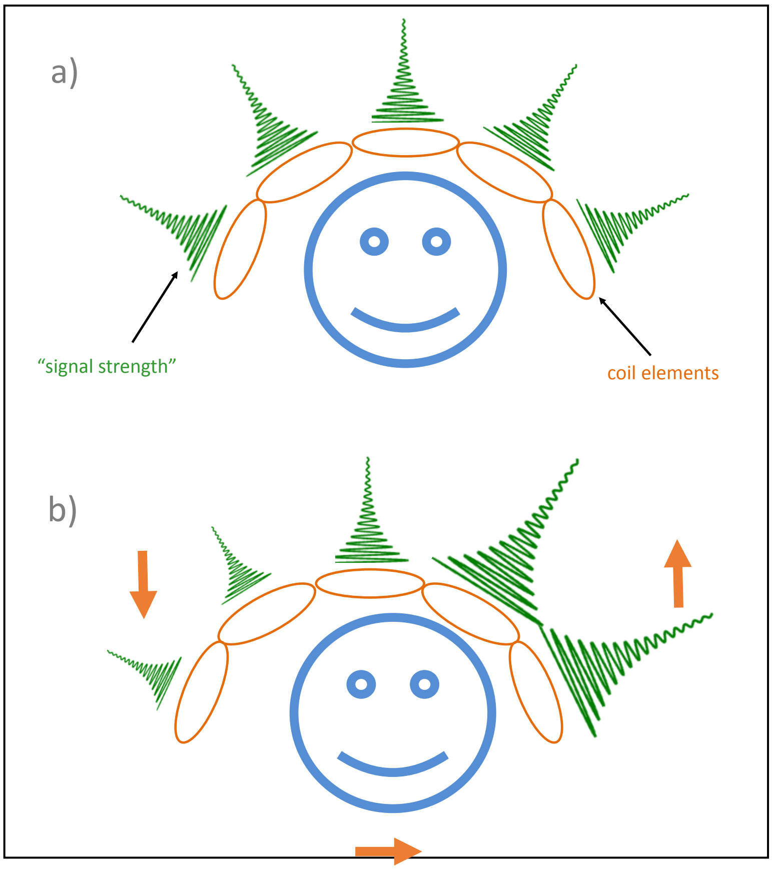

Figure 1 Illustration of the FIDnav working principle: the simplified "signal strength" of a (frequently sampled) free induction decay is changing when a head is moved closer or farther from a coil element (b) with respect to a reference position (a). Note that in reality, both magnitude and phase changes occur.

Figure 1 illustrates the idea of the FIDnav method. Notably, not only the magnitude of the FIDnav signals change if an object is moved inside the coil, but also the phases; this is mainly due to the displacement of the main sources of susceptibility gradients in the head.

MOTION DETECTION USING FID NAVIGATORS

As illustrated above and discussed in more detail in [2,3], rigid-body motion can be reliably detected by FIDnavs and with a sub-millimetre precision (see also [5]). In terms of prospective motion correction, a mere detection does however not allow for correcting the FOV and hence improving the final image quality.

In this most simple "binary" usage of the FIDnavs (i.e. giving "motion happened" or "no motion" information), another correction module has to be employed to measure the motion parameters and subsequently correct the FOV. This correction module is usually associated with additional scan time. The advantage of this combination of a very short detection and a longer, costly correction module is that additional scan time has to be invested only if motion actually occurs, assuming that the FIDnavs come with negligible time penalty, which is typically the case.

In a practical example of this detection/correction scheme, a FIDnav was implemented in a diffusion EPI sequence. The FIDnav was placed after the slice rewinder of the 2D excitation pulse (see Figure 2). The advantage of this timing is that the FIDnav is sampled before the diffusion encoding, i.e. it is theoretically unaffected by the direction and strength of the diffusion gradients. Care has to be taken, however, since the eddy current history of the diffusion gradients played out before affect the FIDnav signals.

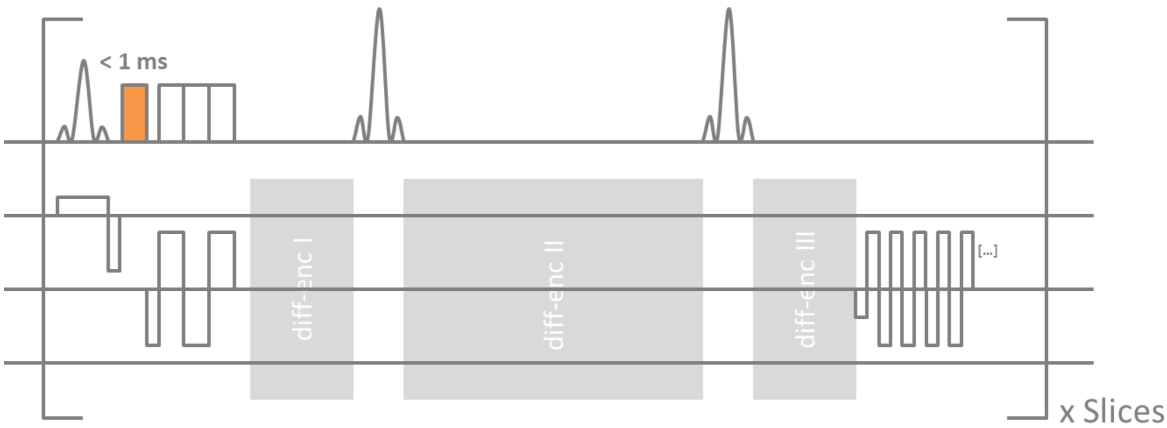

Figure 2 FIDnav implementation in a 2D EPI diffusion sequence: the FIDnav is sampled after the slice rewinder of the excitation pulse and before the application of the diffusion encoding gradients. This ensures that the FIDnav signals are independent of the diffusion encoding strength and direction, an assumption which is only partly true (see text and [3]).

If a motion is detected in the combined FIDnav changes, i.e. the changes of the FID in all coil elements compared to reference FID signals at the beginning of the scan exceed a given threshold, a correction module is interleaved in the imaging sequence. In the example of the diffusion sequence, the correction module is a b=0 scan, i.e. an EPI volume acquisition bare of any diffusion encoding. This b=0 image volume can be registered in real-time to the first, regularly acquired b=0 scan and the resulting motion parameters used to update the position of the FOV.

Note that several limitations apply here: as mentioned, the FID signal is influenced by the eddy current history of the scan. Also, physiological effects as respiration have to be taken into account since they change the FID's phase (see [6]). Lastly, the scanner frequency might drift during the course of the scan, which changes the FIDnav signal as well; this effect in particular is hard to distinguish from slow head motion often happening in head scans.

A current field of research is the use of the FIDnav signals to improve retrospective motion correction algorithms [9]. It was shown that binary information extracted from FIDnavs whether a given portion of k-space is affected by motion or not only speed up the computation but also improve the correction results (see [9]).

MOTION PARAMETERS DERIVED FROM FIDNAVS

It was shown in the works presented above that head motion can be reliably detected by FIDnavs. However, no spatial information about the motion is gained, but a mere binary motion occurred/did not occur decision is made. Given a good coverage of the imaged object, which is the case in typical helmet-shaped modern head coils, it can be hypothesised that the FIDnav signal changes seen in the, say, 32 coil elements contain enough spatial information to quantify the motion. Indeed, recent work shows that this is possible for rigid-body head motion [5].

The work presented in [5] relied on two motion information inputs: FIDnavs sampled in a gradient-echo sequence and an external optical camera system [7,8]. The camera system's motion measurements served as a ground truth, i.e. were assumed to be the true motion. Using the ground truth data and the corresponding (complex) FIDnav signal changes of only a portion of the whole dataset, a general linear model was trained. This model hence linked FIDnav changes to 6 degree-of-freedom rigid-body motion parameters. The remainder of the data was used to compare the predictions made by the GLM feeding in the FIDnav signal changes to the ground truth motion. It turned out that FIDnavs+GLM can indeed very reliably predict motion parameters (see Figure 3).

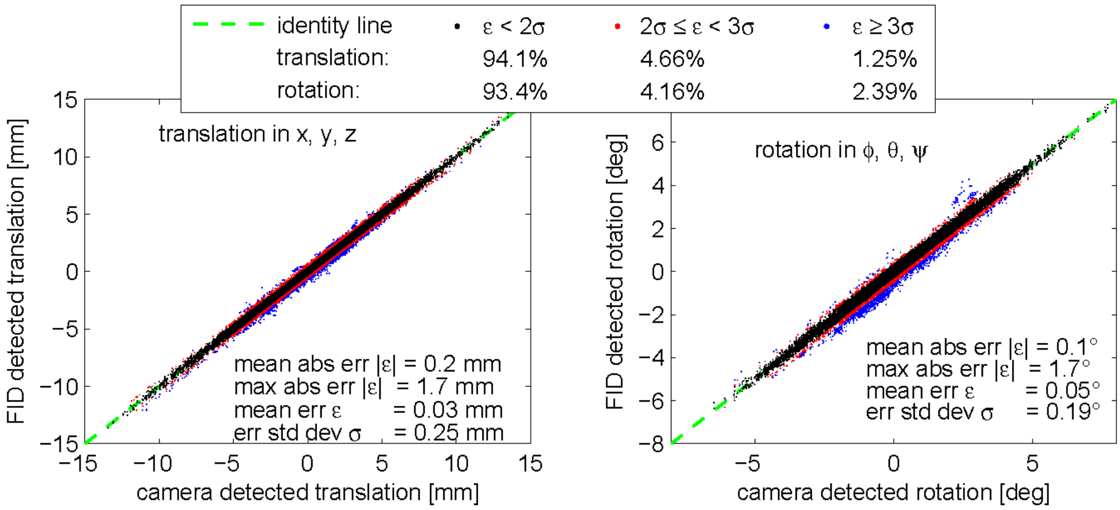

Figure 3 Predicted motion translational and rotational motion parameters by FIDnavs versus ground-truth camera information. It can be seen that the FIDnav-based predictions exhibit very good agreement with the camera data.

It should be noted, however, that the described setup is rather artificial since the GLM model has to be trained using a camera system; having a camera system available, however, should render any other moco technique unnecessary. In the future, other means to train the GLM should be evaluated; this is currently a field of research.

SUMMARY

No-space navigators, i.e. unencoded MR signal samples or FIDnavs, can be sampled very fast with virtually no impact on the timing of the host sequence. They can be used in a binary fashion to detect motion. Subsequently, other techniques can be employed to correct the FOV, yielding a separate detection/correction scheme which only costs time when motion actually happens. Moreover, the binary information can improve results of retrospective motion correction techniques.

No-space navigator changes seem to contain even rigid-body motion information. Currently, a camera system has to be used to train a signal model to derive the motion parameters from the navigators. If other means to train the model could be found, FIDnavs would provide a very fast rigid-body motion correction navigation.

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