Projection-based 2D/3D registration of collapsed FatNav data for prospective motion correction

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Introduction: Collapsed FatNav (cFatNav) is a navigator module that was recently proposed in [1] specifically aimed for prospective motion correction. A cFatNav sub-sequence consists of three EPI readouts sampling orthogonal planes in k-space placed between a non spatially-selective, fat saturation pulse and the host sequence excitation. From each sampled k-space plane, via inverse Fourier transform, we can obtain a view of the excited volume projected along three orthogonal directions as depicted in Fig. 1. We have shown in [1] that 2D registration applied to cFatNav data produces precise motion estimates when the motion occur mostly along one of the three sampled planes. In this work we apply a 2D/3D registration algorithm to cFatNav data so that arbitrary out-of-plane motion can be handled. 2D/3D registration is traditionally used in image-guided interventions - e.g. radiation therapy or radiosurgery - to align CT or MR pre-interventional 3D volumes with X-ray intra-interventional images [2]. The registration algorithm presented can be considered a special case where the focus distance is infinite.

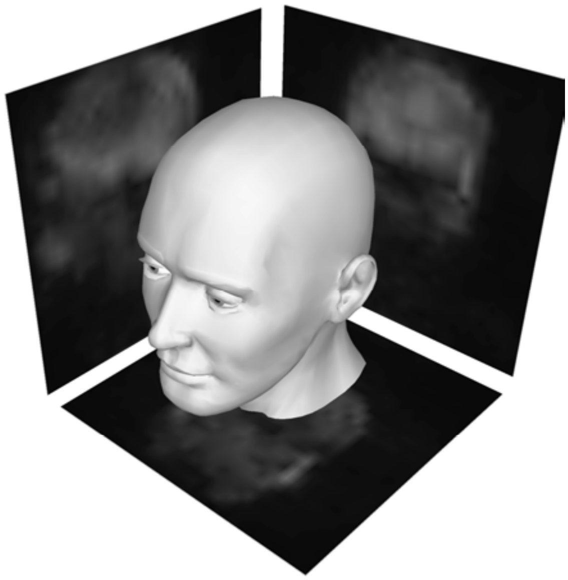

Figure 1: The three orthogonal views of projected fat signal.

Methods: The principle behind 2D/3D registration is to iteratively project a translated and rotated 3D reference volume onto one or more projection planes resulting in 2D images that are registered to the corresponding measured projections. From this registration the six rigid body motion parameters can be obtained. In our case, a cFatNav readout produces three projection images with different distortions due to the different EPI phase encoding directions. Therefore, we have chosen to acquire three different 3D reference volumes each with matching distortion directions and magnitude. This was accomplished by adding Z phase encoding gradients to the cFatNav module at the beginning of the scan. The data-flow of the registration algorithm is shown in Fig. 3. A Gauss-Newton method was applied to solve the least-squares problem of matching each of the projection images simultaneously. Data were acquired on a 3T GE DV750 scanner using a standard 8-ch brain coil. A cFatNav module was embedded in a T2-w spin echo host sequence and run four times on a healhy volunteer. In the first two scans, the prospective motion correction was activated while in the last two no updates were performed. The volunteer was instructed to lie still for scans one and three. In the other two scans the volunteer performed a predetermined motion with both a pitch and a yaw rotation components (~18 degrees) at a voice command form the operator. The following are the relevant sequence parameters; Navigator: FOV = 300mm, matrix size = 32x32 (32x32x32 for the calibration data) and acceleration factor R = 4. Host sequence: FOV = 280mm, TR = 2000ms, TE = 90ms, matrix size = 128x128, NEX = 2. The navigator data and motion estimates were routed by a real-time data server via inter-process communication to a stand-alone reconstruction executable.

Results: The results of the experiments are shown in Fig 2. By comparing images a) and c), one can see that the proposed prospective motion correction, when active, does not degrade image quality for a still subject. Additionally, as image b) shows, the registration algorithm was successful in estimating the performed motion and eliminate the motion artifacts present in image d), which was acquired in absence of real-time updates.

Discussion and Conclusion: Projection-based 2D/3D registration applied to cFatNav data has proved to be capable of handling large out-of-plane movements. At the same time, the proposed scheme has enough accuracy and precision to not degrade the image quality of images acquired without motion. It remains to verify if the latency (around 160ms with the hardware setup utilized) is sufficiently low to cope with continuous motion. Such an experiment will be conducted next with a reconstruction strategy enhanced with a prediction filtering technique. Collapsed FatNav coupled with the proposed registration algorithm is, to the authors' knowledge, the shortest image-based navigator that handles arbitrary rigid motion. With a readout duration of as little as 4.6ms it is applicable to all sequences that contain a fat saturation pulse with minimal increase in scan time. When a fat saturation pulse is not present in the main sequence, a short, low flip angle excitation can be performed instead at the price of a slight further increase in scan time. Finally cFatNav does not require any special hardware and could be deployed via a software update to a big portion of the MR scanners in clinical use.

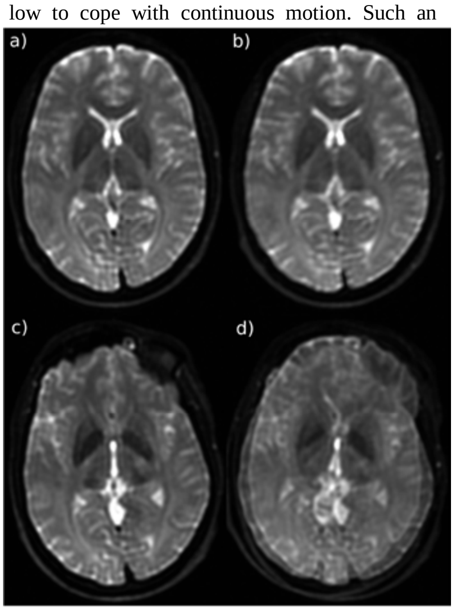

Figure 2: a) correction on, no motion; b) correction on, motion; c) correction off, no motion; d) correction off, motion

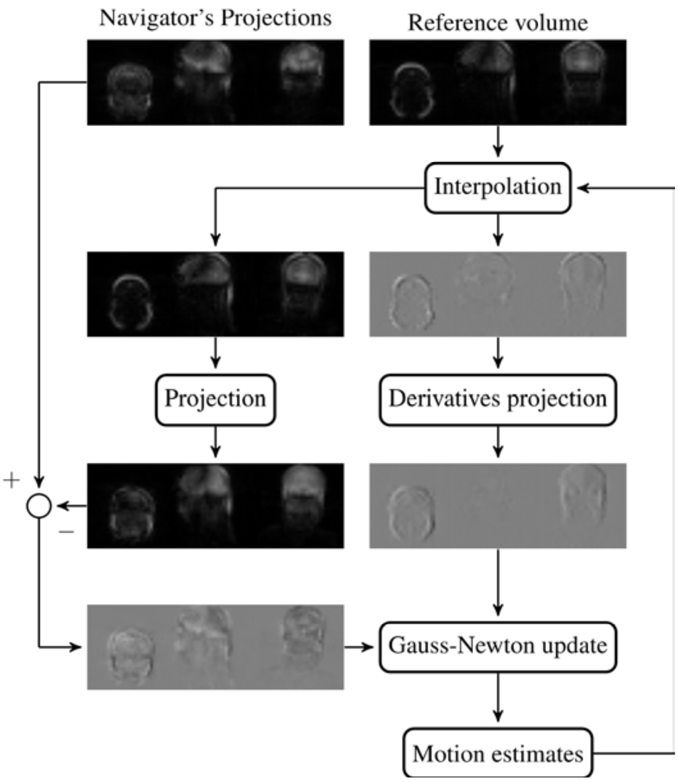

Figure 3: Projection-based 2D/3D registration algorithm

References:
[1] Engström et al. ISMRM 2014
[2] Markelj et al. Medical Image Analysis 16, 2012