Real-Time Prospective Correction of Complex Multiplanar Motion in fMRI

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Introduction

Real-time prospective correction of global inter-image head motion in fMRI has previously been demonstrated for linear and rotational motion in a single plane [1,2]. With this approach, a group of echo planar images in an fMRI time series is preceded by a navigator echo which is then used to prospectively correct for inter-image head motion. Both linear and rotational planar motions are encoded in the signal properties of a single coplanar orbital navigator echo (ONAV) [3,4]. To correct for multiaxial motions, we have demonstrated that by minimizing saturation effects, multiple orbital navigator echoes are capable of detecting their respective planar motions [5]. To date, this method has been tested exclusively on uniplanar motions in the plane of interest. The objective of this work was to test the ability of the navigator echoes to detect motion in their respective planes during *complex*, i.e. simultaneous multiplanar, motions using a realistic model of the head as a phantom. We hypothesize that accurate detection of motion in each of the sagittal, axial and coronal planes is possible. To test this hypothesis, a motion phantom capable of rotation in two orthogonal planes and translation in a single direction was designed such that various complex motions could be reliably created and assessed with the ONAV method.

Methods

The experiments were implemented on a 1.5T imager, with a delay of 11 ms between application of each of the coronal, sagittal and axial ONAVs. The EPI images which would normally follow the ONAVs during clinical studies were not acquired for these experiments. A gradient echo ONAV with TE=3 ms, and slice thickness chosen to encompass the entire phantom, was used to minimize saturation effects. A computer-controlled motion phantom verified as being capable of generating rotations to the nearest sixth of a degree in the sagittal plane, rotations to the nearest degree in the axial plane, and translations to the nearest millimeter in the physical Z direction of the magnet, was programmed to perform given sequences of complex motion. A model skull was created with a CAD-CAM system from a human CT dataset. The model was filled with gel to simulate the properties of the human head *in vivo*, and affixed within the motion apparatus.

Several experiments were performed, two of which are described here. Of interest was not only the accuracy with which actual motions were detected, but also the erroneous detection of motion in orthogonal planes where no motion was executed. In Experiment 1, the phantom was rotated from 0° to ±α° in the sagittal plane, where α ranged from 0 to 10°, during a concomitant fixed Z translation of 0 mm, 3 mm, or 7 mm. In Experiment 2, the phantom was rotated from 0° to ±α° in the sagittal plane, where α ranged from 0 to 10°, during a concomitant fixed axial rotation of 0°, 3° or 7°. The independent variables were the programmed sequences of motion, and the dependent variables were the motions detected by ONAVs played out in each of the three planes. For both experiments, the detected Z translation and detected rotations in all three planes were compared to the actual, programmed motions.

Results

In Experiment 1, highly accurate detection of sagittal rotation throughout the range of 0° to ±10° was found in the presence of each of the three different increments of Z translation, with a slope of 1.05 between actual rotations and detected rotations in the sagittal plane (Fig. 1). Z translations were detected to within ±0.2 mm over the entire range of sagittal rotations. Detected axial rotations were within ±0.7° of the true value of 0° for all sagittal rotations and Z translations. However, coronal rotations of -2.46° to 0° were detected when ideally no rotation should have been detected in the coronal plane.

In Experiment 2, highly accurate detection of sagittal rotation throughout the range of 0° to ±10° was found in the presence of each of the three different angles of axial rotation (Fig. 2). The slope between actual rotations and detected rotations in the sagittal plane was 1.05 in the presence of 0° and 3° axial rotations, and 1.04 for 7° axial rotations. Axial rotations were detected to within ±1° of the actual axial rotation. Detected Z translations were within ±0.5 mm of the true value of 0 mm for all sagittal and axial rotations. However, coronal rotations of -1.75° to 2.5° were detected when ideally no rotation should have been detected in the coronal plane.

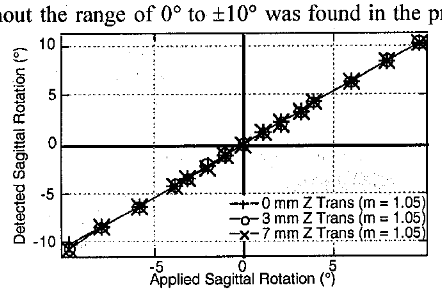

Figure 1: Sensitivity of sagittal ONAV during simultaneous Z translation

Discussion

Sagittal head "nodding" rotation is often cited as the most common cause of motion corrupted fMRI studies. Highly accurate detection of simultaneous sagittal rotation and Z translation can be obtained from a single sagittal ONAV. Accurate detection of simultaneous sagittal rotations and axial rotations was obtained from the respective coplanar ONAVs. These results demonstrate the sensitivity of this method.

Erroneous detection of rotation in the coronal plane was found during both experiments. Rotation in an orthogonal plane may change the ONAV waveform, limiting the accuracy with which the ONAV can detect motion. Thus, large orthogonal rotations reduce the sensitivity of an ONAV to detect in-plane rotations. In these experiments, motion detection in the sagittal and axial planes was not significantly compromised by motion in orthogonal planes, whereas erroneous detection of motion in the coronal plane was seen in the presence of orthogonal motions. However, many parameters have yet to be optimized, thus the problem of erroneous detection of motion in planes orthogonal to an actual rotation remains open to solution.

Conclusions

Real time prospective detection and correction of head motion with ONAVs in fMRI time series is an attractive alternative to retrospective registration methods. We have demonstrated the potential to correct simultaneous multiplanar motions with this approach. Sagittal rotations can be detected to within ±0.35°, axial rotations can be detected to within ±1°, and Z translations can be detected to within ±0.5 mm. However, limitations in the accuracy of coronal motion detection are still being addressed.

References

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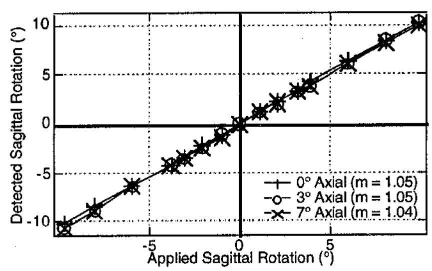

Figure 2: Sensitivity of sagittal ONAV during simultaneous axial rotation