Combining Active Markers and Optical Tracking for Prospective Head Motion Correction

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Introduction Active MR markers [1] and optical tracking systems (i.e. cameras) [2,3] have been successfully used for correcting motion artifacts in head MRI. Unlike active markers, optical tracking systems have the advantage that they work independent from the MRI scanning, and thus require no additional navigator data to detect motion. However, optical tracking systems require cross-calibration between the scanner and camera. Scanner-camera cross-calibration is especially important in a clinical setting since the camera rig needs to be mounted on different head coils at the beginning of each examination and needs to be unmounted at the end of the exam. However, cross-calibration is not a problem for active markers since the motion detection is already done in the MR frame of reference. In this study, we combined active marker and optical tracking to benefit from the advantages of both systems. Specifically, the active markers were used to perform cross-calibration of the optical tracking system in a very short time with no discomfort to the patient so that the motion tracking can be done with the camera. Preliminary cross-calibration experiments demonstrate the feasibility of this combined system.

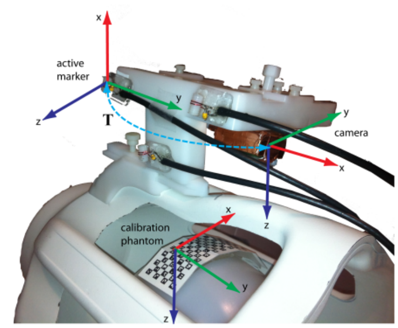

Figure 1 – *The combined active marker & camera system for head motion correction. The active markers were mounted rigidly on the camera rig and were used to perform scanner-camera cross-calibration in ~35 ms.*

Methods The setup used in this study is shown in Fig. 1. The active markers consist of water-filled glass spheres in a small coil. These active markers were attached rigidly on a rig that holds the camera and was mounted on the head coil. The camera was powered by a 12V lead-acid battery and the video signal transmission was accomplished via fiber-optic link in order to reduce interference in the MR images.

There are two stages for performing scanner-camera cross-calibration:

(1) *active marker-camera cross-calibration*: the geometrical relation between the active markers and the camera was established (**T** in Fig. 1). Note that this part needs to be done only once and the results of this stage stay constant as long as the rigidity between the camera and active markers remain. For this purpose, we used a calibration phantom that had a checkerboard pattern on it and had agar-filled holes drilled on the other side (Fig.1). The geometry relation between the checkerboard pattern and agar-filled holes were known. By imaging the calibration phantom simultaneously with the camera and the scanner, the camera position with respect to the scanner could be established [3,4]. Thereafter, the 1D active marker tracking sequence was executed [1] to determine the position of active markers inside the scanner. Combining this information gave the position of the active markers with respect to the camera (**T** in Fig. 1). **(2)** *scanner-camera cross-calibration repeated every time the active marker & camera assembly was mounted on the head coil:* Since the relation between the active marker and camera was known from the previous step, running the 1D tracking sequence was enough to determine the relationship between camera and scanner.

To assess the feasibility of the new scanner-camera cross-calibration method, the initial cross calibration between the active markers and the camera was done as explained above. Later, the whole rig system was displaced in the z direction of the scanner bore to simulate different rig placements as a result of different landmark positions between scans. The scanner-camera cross-calibration in the new positions was done using the *standard cross-calibration* that uses the calibration phantom [3,4] and the new *active marker approach* and the results were compared. We also assessed whether correction of B0 inhomogeneities by negating the readout direction [1] improved the accuracy of active marker approach for cross calibration.

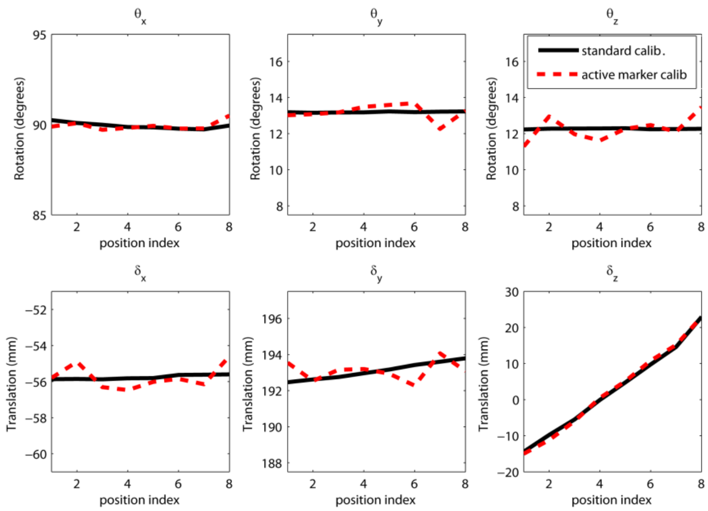

Figure 2 – *Comparison of scanner-camera cross-calibration results using standard calibration and active markers. 3 rotations and 3 translations defining the scanner-camera cross calibration are shown as a function of different positions where the cross-calibration was performed. The black line shows the scanner-camera cross-calibration values with the standard approach and the dotted red line shows the values with the active marker approach. The difference between the two methods was on the order of 1mm and 1°.*

	θ_x(deg)	θ_y(deg)	θ_z(deg)	Δ_x(mm)	Δ_y(mm)	Δ_z(mm)
Positive readout	0.79	1.36	7.51	4.02	7.75	7.44
Negativereadout	0.26	0.32	6.16	25.01	2.05	42.33
B0-corrected	0.17	0.30	0.53	0.51	0.54	0.62

Table 1 – *Error in scanner-camera cross-calibration in the case when positive 1D readouts, negative 1D readouts or both (i.e., B0 corrected) were used.*

Results and Discussion Fig. 2 shows the comparison of cross-calibration results using the standard approach and the active markers and Table 1 shows the cross-calibration errors with active marker calibration with and without B0 correction. The mean error between standard (i.e. gold-standard) calibration and active marker calibration was on the order of 1mm and 1°, with maximum values reaching 2mm and 1° (Fig. 2). Active marker calibration with B0 correction gave more accurate results compared to those that used only the positive or only the negative readout directions. The remaining errors on the calibration emanate from gradient nonlinearities since these tend to increase towards the edges of the field-of-view. Performing gradient-nonlinearity correction on the 1D projection data is expected to improve the results.

Conclusion We demonstrated the feasibility of prospective head motion correction using a combined active marker & camera tracking system. Since the position detection of the active markers requires only 6 1D projection scans (total time = 35ms), cross-calibration between the scanner and the camera frame of references can be accomplished in a very short time without user intervention. The existing scanner-camera cross-calibration methods can be tedious and the proposed active marker based scanner-camera cross-calibration can be used to decrease the setup time of optical motion correction in clinical practice.

References [1] Ooi et al, 2009, MRM [2] Zaitsev et al, Neuroimage, 2006 [3] Aksoy et al, MRM, 2011 [4] Forman et al, Med Imag Anal, 2011 **Acknowledgements** This work was supported in part by the NIH (5R01EB002711, 5R01EB008706, 3R01EB008706, 5R01EB006526, 5R21EB006860, 2P41RR009784), Lucas Foundation, Oak Foundation, and GE Healthcare.