Fast Cross-Calibration Between MR Scanner and Optical System for Prospective Motion Correction

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INTRODUCTION – Utilization of stereovision [1,2] or monovision [3] systems have been suggested as a way to perform rigid head motion correction for MRI. Since no additional MR-based navigator acquisition is required, these systems can be used with any scanning protocol with only minimal changes to the sequence. However, the usability of optical systems in clinical practice has so far been limited. One of the most important reasons for this is the long and tedious cross calibration times that might take minutes required to find the geometric relationship between the optical and the scanner frame-of-reference. This step usually requires the acquisition of calibration data at the beginning of each patient study. Here, we propose a way to perform cross-calibration that is acceptable for clinical use. By using a fast scan with a small field-of-view, we were able to run the cross calibration within ~10 seconds.

MATERIALS and METHODS – (a) The calibration phantom: For cross-calibration, we used the phantom shown in Fig. 1a. It contains both an optical-detectable and an MR-detectable component so that the geometrical relation between the MR and optical frame of references can be determined. To accomplish this, we placed a checkerboard pattern on the top of the phantom that is detectable by a single camera. Each square includes a unique location ID that identifies its position within the pattern. The acrylic layer at the bottom contains cylindrical holes with a diameter of 3mm and these are filled with 5% agar solution (Fig1b). The agar-filled holes coincide vertically with the intersection points of the checkerboard pattern so that the exact geometrical relation between the MR detectable and optical detectable parts of the phantom is known. **(b) Calibration scan:** Cross calibration requires the pose of the agar-filled holes and the checkerboard pattern to be detected simultaneously by the scanner and the camera respectively. Detection of checkerboard by the camera is fast since the processing of camera views is almost real-time. The detection of the agar filled holes is challenging because of the assumption that the patient does not move during this scan. This can only be satisfied if the calibration scan is on the order of seconds. For this purpose, we used a small-FOV 3D fast GRE scan with the parameters given in Fig. 2. The scanning volume was placed tightly around the agar droplets so that the scanning time was minimal. The scan was repeated with varying number of averages and the variation of the calculated pose of agar in the scanner reference frame was used to assess the reliability of the cross-calibration. **(c) Post-processing:** After the calibration scan, the images were transferred to an external processing laptop where the agar filled holes were segmented out and ordered using a semi-automatic segmentation algorithm, and the centroids of the holes were determined. Thereafter, the three axes defining the phantom geometry were extracted by fitting a grid pattern on top of the detected centroids (Fig 1c).

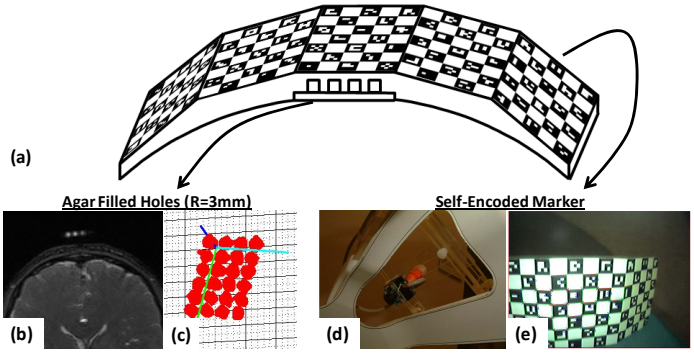
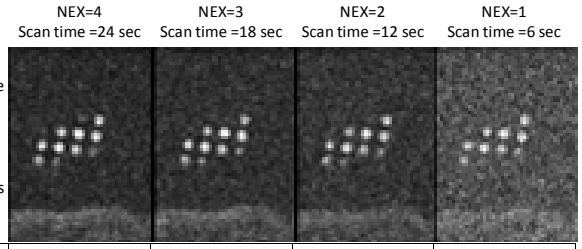


Figure 1. *The phantom used for cross-calibration and real-time position detection (a)*. Position of agar filled holes on the patient (b), post-processing of cross calibration scan (c), the camera rig mounted on the 8ch head coil (d) and the checkerboard phantom as detected by the camera (e) are shown. The phantom contains both MR detectable (agar filled holes) and optical detectable (the checkerboard pattern) components. The exact position of the agar and checkerboard geometry is known. The detection of the pose of the checkerboard with respect to the camera occurs in real time and takes only a couple of mili-seconds. With our current implementation, we were able to bring the cross-calibration scan time down to 6 seconds.



θ_x (degrees)	3.2284	3.3523	2.9501	3.4301
θ_y	101.0471	100.8672	101.0452	100.9503
θ_z	-136.2893	-136.3604	-135.8489	-136.1267
Δ_x (mm)	13.2718	13.1614	13.4835	13.6440
Δ_y	107.0855	107.1863	107.0677	107.1032
Δ_z	37.9521	38.1811	37.9454	38.0150

Figure 2. *Results of cross-calibration scans*. We used a fast GRE sequence with the parameters given above. It can be seen that, even with a single average (NEX=1), the position of the agar inside the scanner geometry was accurately determined.

RESULTS – Figure 2 shows the results of the calibration scans. It can be seen that, for all four scans, the estimated rotation and translation between the phantom and the scanner were very similar. The standard deviations of the 6 transformation parameters (i.e., 3 rotations and 3 translations) were determined to be: $\sigma_{\theta x}$=0.2105°, $\sigma_{\theta y}$=0.0863°, $\sigma_{\theta z}$=0.2271°, $\sigma_{\Delta x}$=0.2156mm, $\sigma_{\Delta y}$=0.0525mm, $\sigma_{\Delta z}$=0.1097mm. This data suggest that it is possible to perform the cross-calibration step in 6 seconds and within an accuracy of ±0.2° and ±0.2mm.

DISCUSSION – Migrating real-time prospective motion correction methods that use optical systems to clinical practice requires easy setup and short calibration times, thereby minimizing the extra overhead associated with such external devices and increasing acceptance in clinical routine. In this study, we introduced a short cross-calibration scan that requires only a few seconds. Hence, it will significantly reduce the time needed to setup an optical tracking system.

References [1] Zaitsev *et al.* NeuroImage, 31:1038-1050, 2006 [2] Qin *et al.* MRM, 62:924-934, 2009 [3] Aksoy *et al.* ISMRM, 2008
Acknowledgements This work was supported in part by the NIH (1R01EB008706, 5R01EB002711, 1R01EB006526, 1R21EB006860), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, Oak Foundation and GE Healthcare.