# A Real Time Optical Motion Correction System Using a Single Camera and 2D Marker

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**INTRODUCTION –** Due to the prolonged acquisition time, motion correction in MRI becomes a must for achieving clinically acceptable image quality. This becomes especially important in the case of children and patients suffering from a medical condition that keeps them from staying still. Motion correction schemes can be classified as retrospective, where the motion correction is done after the data acquisition is completed, and prospective, where the motion correction is achieved in real-time during data acquisition. In general, retrospective schemes suffer from limited resolution and inability to correct for all types of motion [1]. Previous prospective motion correction schemes utilized optical systems where the camera system had to be placed outside the scanner bore, but this requires sub-millimeter stereo position accuracy over a field of view of several meters [2,3]. In this study, we use a shielded in-bore camera system that only requires a single camera and 2D marker, rather than at least two cameras and a 3D marker [4].

**MATERIALS and METHODS –** Accurate position detection from a single camera was accomplished using a number of transformations from the camera's view to that of the MR system. *(a) Intrinsic Camera Calibration*: For detection of marker position with respect to the camera, the intrinsic parameters of the camera such as focal length, principal point, and lens distortion parameters must be determined. Intrinsic calibration was performed using first on a 2D checkerboard pattern. The checkerboard consisted of a 5x6 grid each of which were 5x5 mm. *(b) Real-Time Marker Position Detection*: The same checkerboard pattern can be used for real-time position detection. After detection of the marker, it was possible to find the position of the marker with respect to the camera using built-in OpenCV functions, which is given by the transformation matrix from marker to camera coordinate system ($\mathbf{T}_{\mathbf{marker}\rightarrow\mathbf{camera}}$). *(c) Camera Scanner Calibration:* In order to update the scanner gradient waveforms according to the detected motion of the marker, the relative position of the camera with respect to the scanner isocenter has to be known. A 3-layer acrylic setup where the middle layer consisted of a 4x5 grid of holes with 3 mm diameter was manufactured. Holes were filled with 5% agar solution. The 5x6 checkerboard pattern was placed on top of this setup such that the corners of the squares on the checkerboard coincided vertically with the centers of the holes (Fig1). Then, this setup was scanned using a 3D SPGR sequence, TR=33ms, TE=3ms and 256x256 resolution. In the MRI data, the centers of the agar filled regions were detected using connected component analysis. Then, the grid points detected by the scanner were registered to the grid points that were detected by the camera, from which the transformation matrix $\mathbf{T}_{\mathbf{camera}\rightarrow\mathbf{scanner}}$ was determined. Fig3 shows the relative positions of the marker, the camera and the scanner in a VTK environment after camera-scanner calibration *(d) Updating scanner parameters*: For each transformation matrix $\mathbf{T}^{(\mathbf{i})}_{\mathbf{marker}\rightarrow\mathbf{camera}}$ at time point **i**, the corresponding transformation that has to be applied to the scanner to follow the marker is determined by the following:

$$\mathbf{T}^{(\mathbf{i})}_{\mathbf{scanner}\rightarrow\mathbf{scanner(0)}} = \mathbf{T}_{\mathbf{camera}\rightarrow\mathbf{scanner}}\, \mathbf{T}^{(\mathbf{0})}_{\mathbf{marker}\rightarrow\mathbf{camera}}\, \mathbf{T}^{(\mathbf{i})}_{\mathbf{camera}\rightarrow\mathbf{marker}}\, \mathbf{T}_{\mathbf{scanner}\rightarrow\mathbf{camera}}.$$

Here, $\mathbf{T}^{(\mathbf{0})}_{\mathbf{marker}\rightarrow\mathbf{camera}}$ represents the initial position of the marker with respect to the camera and was determined at the beginning of the scan, as could be determined in calibration. This matrix is representative of the initial patient position. The marker detection and matrix calculations were done using a laptop, which were fed back to the scanner using the TCP/IP protocol [5]. *(e) Pulse sequence*: An interleaved spiral sequence with 32 interleaves, 256x256 resolution, TR/TE=2000/90 was used to test our algorithm. A brain phantom was manually rotated 5 degrees during the scan. The scan was repeated with the real time motion correction turned off. An additional scan with no motion was also obtained for reference.

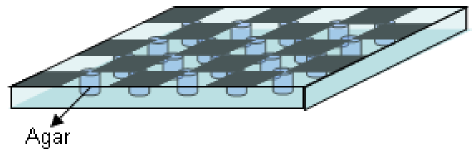


Fig 1 – The grid structure used for camera- scanner calibration. The centers of the agar filled holes were detected by the scanner and the corner points of the checkerboard pattern were detected by the scanner. This allows one to determine the relative position of the camera with respect to the scanner.

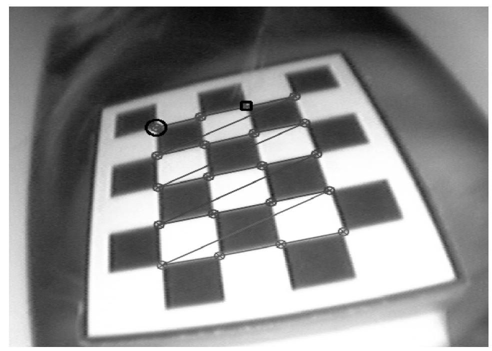

Fig 2 – Real time detection of the marker with the camera. Once the intersection points were determined, they were ordered automatically, as shown by the zig-zag line. The black circle shows the first point in the ordering. Since the marker geometry was also known, it was possible to determine the transformation from the marker frame of reference to the camera frame of reference.

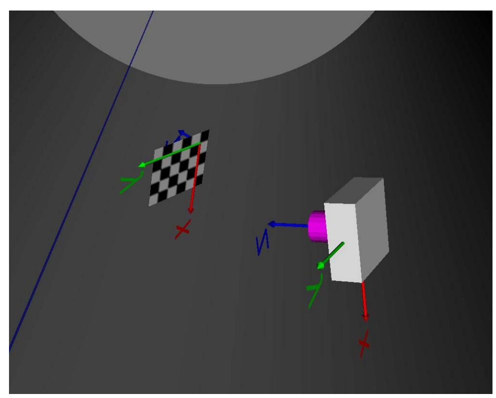

Fig 3 – Close-up view of the relative position of the marker with respect to the camera and the scanner bore in a VTK environment. The positioning of the camera with respect to the scanner, as given by $\mathbf{T}_{\mathbf{camera}\rightarrow\mathbf{scanner}}$, was determined during scanner-camera calibration.

**RESULTS –** Figure 4 shows the images reconstructed with and without real-time motion correction. The motion artifacts introduced by rotation were reduced when the real-time motion correction was turned on. We also observed that the real-time motion correction did not introduce any errors when there was no motion, which means that the stability of position detection in the absence of motion is smaller than half the voxel size, 0.94mm.

**DISCUSSION** – The presented real time optical motion correction system is capable of correcting in quasi real-time for both in-plane and through-plane rigid body motion. Our preliminary results show that the proposed system is effective in correcting for rigid body motion related artifacts. Both the intrinsic camera calibration and extrinsic scanner-camera calibration are semi-automatic and can be carried out each time with a relatively small overhead to the scanner usage time. This scheme can be used with more than one camera, which may add stability to the measurement, but at the cost in increased system complexity.

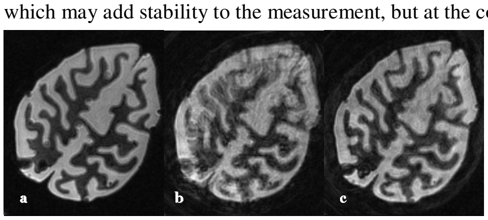


Fig 4 – The phantom image reconstructed with and without real time motion correction. Reference image obtained with no motion is shown on the left (a). The artifacts were apparent when motion was present (b). Application of real time prospective motion correction significantly removed these artifacts (c).

**References** [1] Bammer et al, MRM, 57: 90-102, 2007. [2] Dold et al., Acad. Radiol; 13:1093-1103, 2006 [3] Zaitsev et al., NeuroImage, 31:1038-1050, 2006. [4] Qin et al, ISMRM 2007. [5] Santos et al, Conf Proc IEEE Eng Med Biol Soc., 2:1048-51,2004 **Acknowledgements** This work was supported in part by the NIH (2R01EB002711, 1R21EB006860), the Center of Advanced MR Technology at Stanford (P41RR0978 4), Lucas Foundation and Oak Foundation.