Calibration and quality assurance for optical prospective motion correction using active markers

Julian Maclaren[1], Melvyn B. Ooi[1], Murat Aksoy[1], Jakob Ehrl[1], and Roland Bammer[1]
[1] *Dept. of Radiology, Stanford University, Stanford, CA, United States*

Introduction and purpose: Prospective motion correction is an effective method for preventing motion artifacts in brain MRI [1]. Head tracking information is used to update the imaging volume orientation and position during scanning, thereby compensating for head motion in real-time. Optical methods are a fast and sequence-independent means to obtain the required head tracking data [1-6]. However, they require accurate cross-calibration prior to scanning so that motion data can be converted into the scanner coordinate system [7]. Optical tracking system quality assurance (QA) should also be used to confirm that the system is operating with low latency (i.e., low update delay), high precision, and accuracy [8]. We present a fast (~ two minutes) and accurate method for cross-calibration and QA of an optical system.

Methods: *Hardware* – A calibration tool comprising wireless active markers [9] and an optical marker [4] was constructed (Fig.1) to allow simultaneous motion tracking of the same object in both optical and scanner coordinate systems. The tool is based on a plastic sphere mounted on a curved base, allowing rotations to be performed approximately about the scanner isocenter.

Scanner software – A pulse sequence was created that tracks the active marker positions and simultaneously applies prospective correction to marker tracking using the optical data.

Calibration/QA data collection – The calibration tool was manually rotated ~ 3-10° during a two-minute prospectively corrected scan. The initial cross calibration used here is an estimate based on the known position of the camera in the scanner bore; the final accurate cross calibration is calculated after scanning.

Data processing – Log files from both tracking systems were processed to compute the cross-calibration transform and QA information (Fig. 2). Cross-calibration is performed based on a hand-eye calibration method, similar to that published by Zahneisen et al. [10]. Latency is measured by dividing active marker rotation error by angular velocity, obtained from the optical data. Accuracy of optical tracking is determined relative to the active marker positions for each pose. Precision of optical tracking is calculated by taking the standard deviation of all samples in the first pose (when the calibration tool is stationary).

Final validation – Optical prospective motion correction was performed on a volunteer using the final cross-calibration transform calculated here and a T2 FLAIR sequence (TR: 8.0 s, TI: 2.1 s, TE: 104 ms, 1 mm in plane res., 5 mm slices). Every 20 s during imaging the volunteer was told to rotate his head in a repeatable fashion.

Results: Fig. 3 shows example tracking data from both optical and active marker systems. Fast rotations resulted in residual errors in active marker tracking, due to the latency in the motion calculation and update process. Overall latency was 64 ms, which includes the average delay from a motion event to the next camera frame, processing time, and delay until the next active marker sequence TR. Subtracting the known camera frame and sequence update delays, gives a processing time of about 24 ms. Accuracy, as defined by mean error between optical and active marker systems was 0.08 deg., 0.07 deg., and 0.36 deg. for rotations about x, y and z, respectively, and 0.58 mm, 0.10 mm and 0.31 mm for translations in x, y and z. Precision was < 50 µm in all three directions.

Discussion: Recent work on wireless active markers has enabled high temporal resolution tracking (e.g. 30 Hz) in the scanner coordinate system; however, this method still lacks the temporal resolution of optical systems (potentially > 100 Hz) and requires the tracking pulse sequence to be inserted into the imaging sequence. However, this work indicates that active markers can play an important role in calibrating and validating optical tracking. In particular, this calibration method has a major speed advantage over previous image-based methods [2,10], due to the high tracking rate achievable using the active markers (we have not tried to optimize imaging time, but enough poses for calibration could be obtained in as little as 10 s). This calibration needs to be performed once per camera installation at a particular scanner.

Conclusion: Rapid cross-calibration and QA of an optical system is possible in a single scan, using a calibration tool that combines active marker and optical tracking, requiring far less scan time than previous methods that require multiple scans. Its ease of use and minimal setup time may facilitate more widespread adoption of optical motion tracking in the clinic.

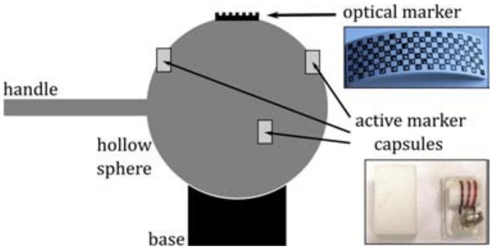

Fig. 1: Calibration tool, comprising both an optical marker and three wireless active markers, combined in a rigid arrangement. All four markers are fixed to a hollow plastic sphere (diameter = 10 cm), which is placed at approximately the scanner isocenter. Rotations in all three directions are applied manually using the plastic handle.

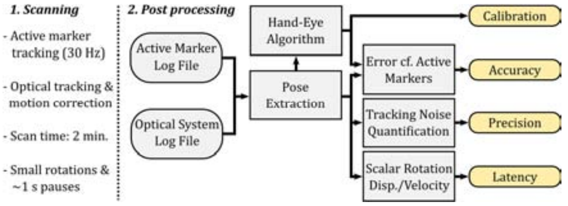

Fig. 2: Imaging experiment and automated data processing applied to extract camera-scanner cross-calibration, and optical system QA information (latency, accuracy and precision), from a single experiment.

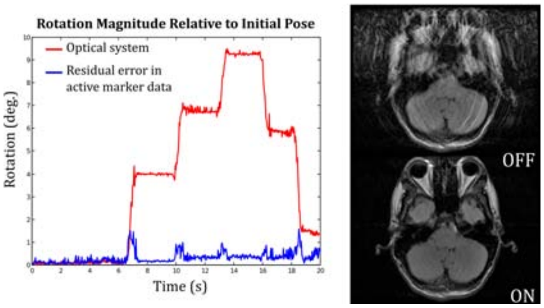

Fig. 3: (Left) Rotation magnitudes (which are calibration independent) from the first 20 s of the QA experiment, showing the motion that occurred. Fast rotations between poses result in errors in the motion-corrected active marker data (ideally zero, with perfect correction); the height of these error peaks divided by estimated velocity from the optical data forms the basis for the latency calculation. (Right) Results of the T2 FLAIR imaging experiment without and with motion correction using the cross-calibration calculated here.

References: [1] Maclaren, et al. MRM 2012; 69:621-36. [2] Zaitsev et al. NeuroImage 2016; 31:1038-50. [3] Qin et al., MRM 2009;62:924-34. [4] Aksoy, et al., MRM 2011;66:366-78. [5] Schulz et al., MAGMA 2012;24:443-53. [6] Maclaren et al., PLOS ONE 2012; 7:e48088. [7] Zahneisen et al., MRM early view, 10.1002/mrm.24943. [8] Maclaren et al. MRM 2010; 63:162-70. [9] Ooi et al., MRM 2013; 70:639-47. [10] Zahneisen et. al, MRM early view, 10.1002/mrm.24806.

Acknowledgements: NIH (2R01 EB002711 , 5R01 EB008706, 5R01 EB011654), the CMART at Stanford (P41 RR009784), Lucas Foundation.