Optical Motion Tracking With Two Markers for Robust Prospective Motion Correction

Aditya Singh[1], Benjamin Zahneisen[1], Brian Keating[1], Michael Herbst[2], Maxim Zaitsev[2], and Thomas Ernst[1]
[1]JABSOM, University of Hawaii, Honolulu, Hawaii, United States, [2]University Medical Center Freiburg, Freiburg, Germany

INTRODUCTION

Prospective motion correction (PMC) for MRI using camera-based tracking has proven effective in mitigating the effects of subject motion without increasing the scanning time,[1] but relies on the assumptions that the marker being tracked is visible all the time and that the imaged object is a rigid-body that moves together with the marker. For brain MRI, these assumptions can be violated when larger head movements cause the marker to be obscured by RF coil structures or when a subject frowns or squints, resulting in motion of the skin relative to the brain. We provide a solution to these problems by using two markers placed on a subject's forehead to achieve 1) adaptive marker tracking and 2) detection of non rigid-body motion and suppression of resulting erroneous motion correction. Together, these techniques eliminate two common failure modes of PMC and thus create a more robust PMC system.

THEORY

We assume two markers M_1 and M_2 attached to a rigid-body. Let $\boldsymbol{X}_1(t_0)$ and $\boldsymbol{X}_2(t_0)$ be the initial poses (4x4 homogeneous matrices) for M_1 and M_2. At time t, their corresponding poses are $\boldsymbol{X}_1(t)$ and $\boldsymbol{X}_2(t)$. Since the two markers undergo the same motion relative to their initial poses, we have: $\boldsymbol{X}_1(t) \times \boldsymbol{X}_1(t_0)^{-1} = \boldsymbol{X}_2(t) \times \boldsymbol{X}_2(t_0)^{-1}$ [1]. Consequently, if M_1 becomes obstructed and M_2 is visible, then we can reconstruct $\boldsymbol{X}_1(t)$ from $\boldsymbol{X}_2(t)$ as: $\boldsymbol{X}_1(t) = \boldsymbol{X}_2(t) \times \boldsymbol{X}_2(t_0)^{-1} \times \boldsymbol{X}_1(t_0)$ [2]. We denote this process "**adaptive tracking**". Additionally, as per Eq.1, the quantity $\Delta\boldsymbol{X} = (\boldsymbol{X}_2(t) \times \boldsymbol{X}_2(t_0)^{-1}) \times (\boldsymbol{X}_1(t) \times \boldsymbol{X}_1(t_0)^{-1})^{-1}$ should be the identity matrix for rigid-body motion. Conversely, deviation of $\Delta\boldsymbol{X}$ from identity indicates relative marker movement, such as that caused by squinting or other non rigid-body movements.

METHODS

Experiments were performed on a consented volunteer on a Siemens 3T TIM Trio (12-channel head coil, VB17). Images were acquired with a PMC-enabled MPRAGE sequence (TR/TI/TE=2200/1100/4.15, 9^0 flip angle, 1mm isotropic), using the XPACE library[2]. A two-marker module was developed allowing the XPACE library to process data from two markers. Care was taken to ensure that tracking data for both markers originate from the same camera shot.

RESULTS

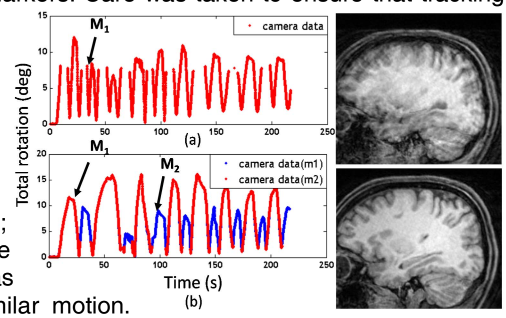

Fig. 1. Results for experiment I. (a) conventional single-marker tracking and (b) adaptive tracking with 2 markers. If marker 1 becomes obscured, the algorithm switches to marker 2 (if visible) to reconstruct the location of marker 1 and provide correct feedback.

EXPERIMENT 1: The subject was instructed to perform a large-amplitude left-right head motion such that the initially tracked marker was intermittently obstructed by the RF coil. Figure 1(top) demonstrates the effect of loss of tracking. The top trace shows tracking data from marker 1 (M_1); intermittent obstructions of the marker by the RF coil appear as gaps in the plot. The resulting image (top right) shows severe motion artifacts, since motion correction was incomplete. Figure 1 (bottom) displays the results from adaptive tracking for a similar motion. Tracking from marker 1 (red) was lost for 8 episodes, during which the XPACE library switched to marker 2 (blue trace). The resulting image (bottom right) has no visible motion artifacts.

EXPERIMENT 2: The subject kept his head motionless, but was instructed by the operator to squint at regular intervals (every 20s) midway through the scan (total number of squints = 7; duration ~2.4s). When the total rotation ($\Delta\boldsymbol{X}$) >1^0, a squint was assumed to occur and the data from that MP-RAGE readout train were discarded and reacquired. The relative orientation between the 2 markers is altered during brief periods of squinting (graphs in Fig. 2). The top right image was acquired with squint detection OFF. Although the total duration of squints (<20 s) is only a fraction of the total scan time (~6 minutes), squinting caused substantial artifacts due to the false correction signals created (Fig. 2, top right). Fig. 2b shows the results with squint detection and correction ON. The reject signal (magenta) turns on as soon as a squint is detected, resulting in suppression and re-acquisition of corrupted K-space lines and ultimately an image with no noticeable artifacts.

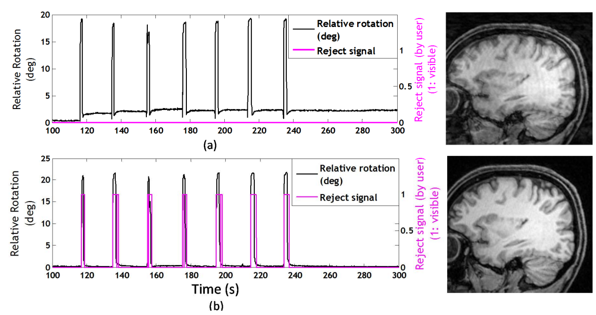

Fig. 2. Experiment II. (a) Single-marker tracking with squinting, and (b) two marker tracking with detection and rejection of skin motion. Rejected data were reacquired resulting in better images.

DISCUSSION & CONCLUSION

A motion correction system capable of operating on data from two skin-attached markers can alleviate problems caused by loss of visual contact with one marker and detect skin movements to prevent false corrections. The system markedly improved the robustness of motion correction. One limitation is the case when only one marker is visible and a squint occurs; this would result in false feedback and some artifact. Although the current methods have been developed for the Moiré-Phase-Tracking (MPT) system[3], they can be applied to any optical system that allows simultaneous tracking of two markers. Finally, the concept can be extended to the use of more than two markers.

ACKNOWLEDGEMENTS: This work was supported by NIH (R01 DA021146, R01 DA021146-06S1, U54 56883, and G12 MD007601).

REFERENCES: 1. Maclaren, J., M. Herbst, et al. (2013). "Prospective motion correction in brain imaging: a review." Magn Reson Med 69(3): 621-636.
2. Zaitsev, M., C. Dold, et al. (2006). "Magnetic resonance imaging of freely moving objects: prospective real-time motion correction using an external optical motion tracking system." Neuroimage 31(3): 1038-1050.
3. http://www.metriainnovation.com/ (Accessed November 13, 2013)