HYBRID MOTION CORRECTION: COMBINING PROSPECTIVE & RETROSPECTIVE MOTION CORRECTION

Malte Laustsen[1], Stefan Glimberg[1], Jakob Slipsager[1], Robert Frost[2], Melanie Ganz[3], André van der Kouwe[2], and Thomas Gaass[1]
[1]TracInnovations, Ballerup, Denmark, [2]Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA, United States, [3]Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark

INTRODUCTION

Prospective Motion Correction (PMC) in brain MRI is sensitive to noisy motion tracking, and to latency between head motion and application of correction, especially when the direction of motion is frequently changing. Hybrid Motion Correction (HybridMC) - a method combining PMC with Retrospective Motion Correction (RMC) - can help alleviate these shortcomings.

METHODS

The study used:

- a PMC-enabled 3D-T1w-MPRAGE sequence. [1]
- a markerless optical motion tracking system (Tracoline TCL 3.2, TracInnovations) supplying 30 head pose estimates per second.
- an RMC-capable reconstruction pipeline utilizing the Fourier Shift Theorem and a non-uniform Fourier transform. [2]

A healthy volunteer performed a motion paradigm with/without PMC, guided by a video of a crosshair, displayed on an MR-compatible screen (NordicNeuroLab). Motion consisted of four slow head nods (8 degrees rotation) with addition of heavy breathing motion in a pseudorandom pattern (1.5 degrees rotation with 20-60 breaths per minute) to investigate effects of delay.

Two methods were investigated (further detailed in **Figure 1** & **2**):

- **Noisy tracking** was mitigated by introducing a motion threshold to only send new PMC estimates when the pose change exceeds a predefined motion score [3] of T=2 mm. The score is reset after sending a new estimate. The residual between motion corrected with PMC, and lowpass-filtered tracked motion is applied using RMC.
- **Delay in correcting for motion using PMC** was compensated with RMC. Using triggers from the scanner, the tracked motion is precisely synchronized to MR acquisition times. The residual between motion corrected with PMC, and lowpass-filtered precisely-synchronized tracked motion is applied using RMC.

The effectiveness of thresholded PMC was investigated by deliberately increasing tracking noise by dimming the projector intensity of the optical tracker to 30% of the optimal setting.

The effectiveness of PMC delay compensation was investigated by deliberately introducing an additional 600 ms delay before sending pose estimates to the scanner.

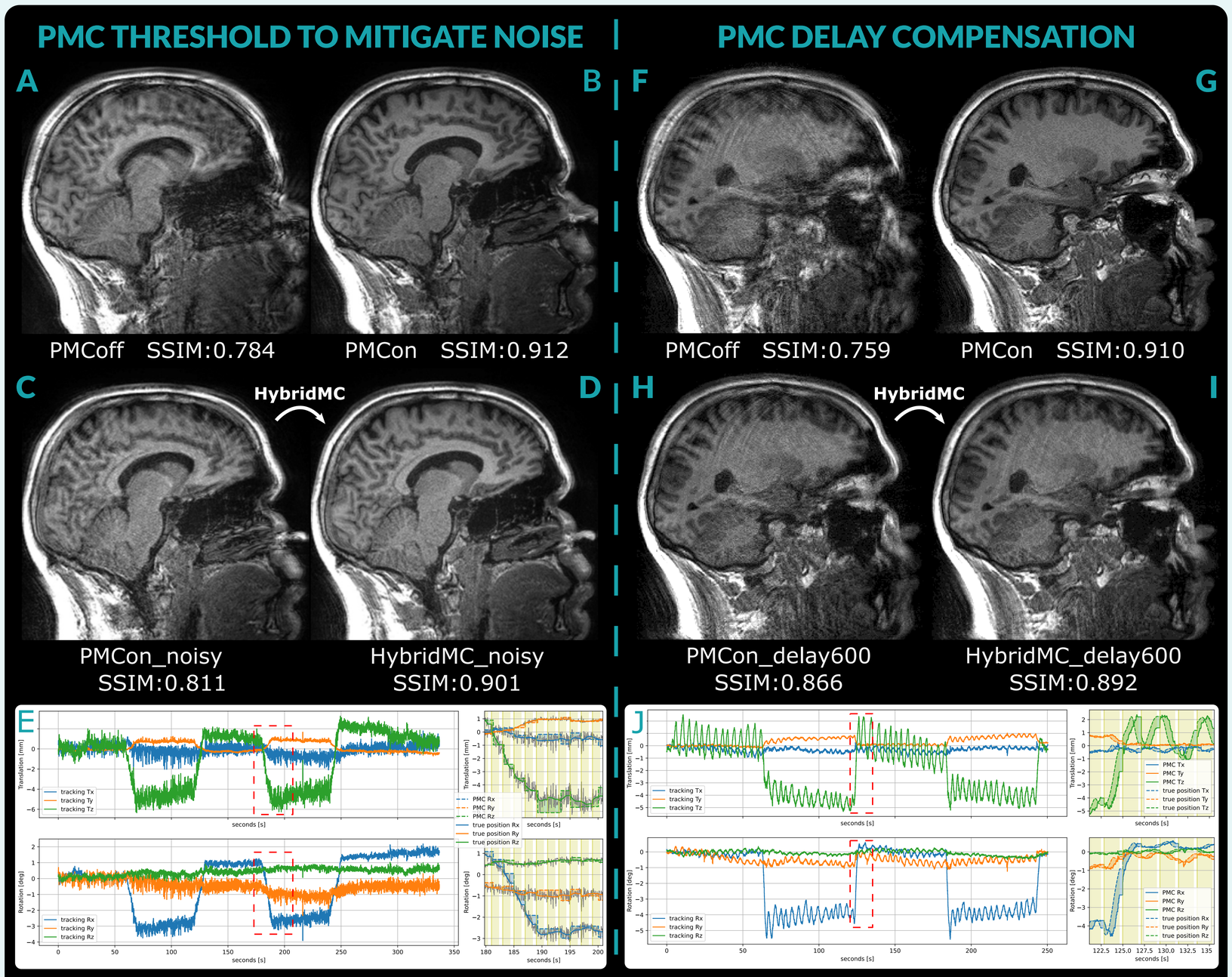

Figure 3: (**A**,**B**)*: Uncorrected motion scan and PMC under ideal tracking conditions;* (**C**,**D**)*: PMC and Hybrid Motion Correction + thresholding during tracking with deliberately induced noise;* (**E**)*: Motion tracking during acquisition of image D with deliberatly induced noise. A zoomed view shows residual tracking (fill) applied using RMC on raw data already corrected with PMC;* (**F**,**G**)*: Uncorrected motion scan and PMC under ideal tracking conditions;* (**H**,**I**)*: PMC and Hybrid Motion Correction during tracking with an induced delay of 600ms;* (**J**)*: Motion tracking during acquisition of images H&I with an induced delay of 600ms. A zoomed view shows residual tracking (fill) applied using RMC to correct for delay during PMC. All images, including a reference image without intentional motion and no PMC, were reconstructed using the same pipeline. Image quality was assessed using the Structural Similarity Index Measure (SSIM) with the reference image. (3T Prisma, 64ch head coil, Siemens Healthineers, Erlangen, Germany).*

RESULTS

- Compared to PMC alone, HybridMC with thresholding achieved superior image quality and SSIM when confronted with noisy tracking (see **Figure 3 C-E**).
- When PMC was applied with artificially delayed motion estimates, the hybrid approach demonstrated improved image quality and SSIM (see **Figure 2 H-J**).
- HybridMC retained similar performance as PMC under optimal tracking conditions.

DISCUSSION

- HybridMC mitigates artifacts in PMC, particularly under conditions where low tracking SNR and periodic motion degrade PMC performance, expanding the applicability of PMC.
- Prior studies have explored HybridMC in phantom scans and simulations[2,4,5]. This study demonstrates applicability in vivo.
- Future research should investigate HybridMC across various motion types, patient populations, and sequences.

REFERENCES

[1] Frost R, et al. 2019 [doi: 10.1002/mrm.27705].
[2] Slipsager JM, et al. 2022 [doi: 10.1002/mrm.28991].
[3] Tisdall MD, et al. 2012 [doi: 10.1002/mrm.23228].
[4] Maclaren J, et al. 2011 [doi: 10.1002/mrm.22754].
[5] Hucker P, et al. 2021 [doi: 10.1002/mrm.28783].
Funding: grant NIH S10OD025253

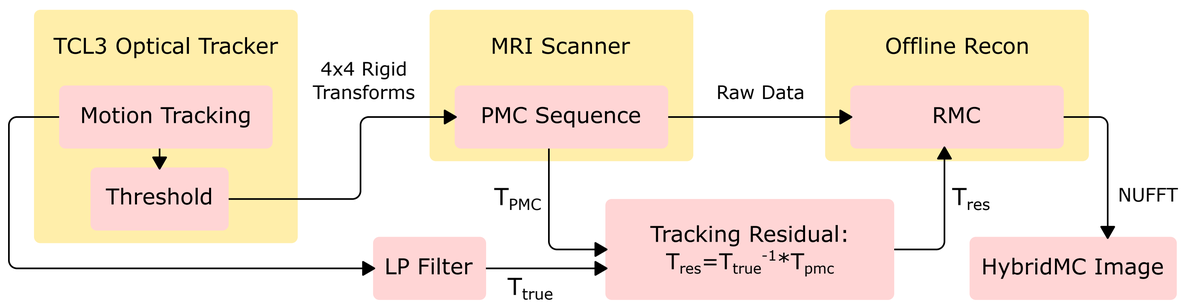

Figure 1: HybridMC and thresholding used for suppression of artifacts induced by noisy tracking; *A threshold is used to only send new pose estimates to the PMC-sequence when motion exceeds a motion score (3) of T=2 mm. After the scan, the true position of the patient (T_{true}) is approximated by low-pass filtering the motion tracking (cutoff=0.5Hz). The residual tracking (T_{res}) between T_{true} and the tracking used during PMC (T_{pmc}) is applied using RMC on already PMC-corrected raw data.*

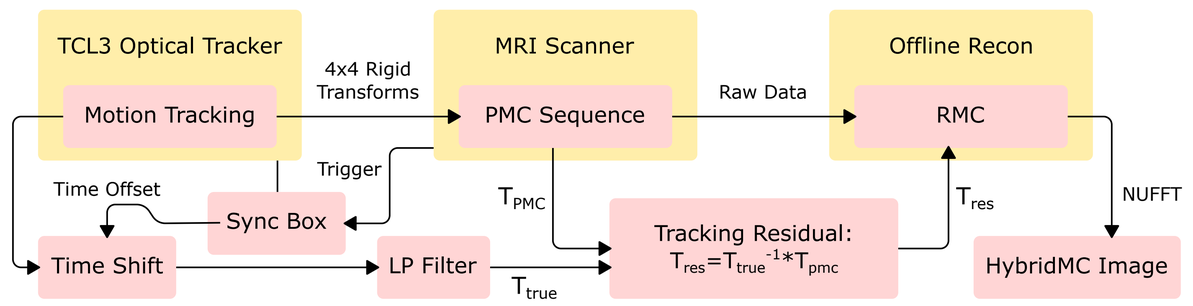

Figure 2: HybridMC used to compensate delay during PMC; *Pose estimates sent to the PMC sequence are affected by delay due to recording/reconstructing data used for motion estimation, delivery of estimates, and wait time for next PMC opportunity. After scanning, the true position of the patient (T_{true}) is approximated by tightly synchronizing the motion tracking to MR acquisition using triggers from the scanner, and by low-pass filtering (cutoff=5Hz). The residual tracking (T_{res}) between T_{true} and the tracking used during PMC (T_{pmc}) is corrected using RMC on already PMC-corrected raw data to compensate for delay.*