Measurement of microscopic head motion during brain imaging

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Introduction

Prospective motion correction has been shown to prevent artifacts caused by head motion during MR imaging of the brain [1-5]. To achieve this, the technique requires accurate quantification of motion in six degrees of freedom and in real time, ideally with a system that operates independently from the MR scanner [1]. However, existing setups lack the accuracy necessary to measure and correct the small involuntary head motion (~200 µm) that results from the respiratory and cardiac cycles and from uncontrolled muscle activity. The goal of this work was to develop a camera system to make this possible at field strengths of up to 7 T.

Methods

Hardware: The external camera used in the tracking system in [6] was replaced with an in-bore system (Fig. 1) designed by the authors for accurate head tracking during simultaneous MR imaging. Specifications include a frame rate of higher than 80 fps; a controlled exposure time; a global shutter; a plastic enclosure lined with 50 µm copper shielding to prevent RF interference, while avoiding eddy-current induced vibrations; optical output (IEEE 1394b) for high-speed image transfer; a single shielded DC supply; and on-axis target illumination through a half-silvered mirror. The optics were designed so that the system can track a target located anywhere between 5 and 65 cm from the camera (Fig. 1c).

MR-Compatibility and Performance Testing: RF testing was performed on the system at both 3 T and 7 T by sweeping the entire receive bandwidth and recording data. Tracking precision, vibrations, drift and latency were also measured. Field mapping at 3 T was performed on a 16 cm water phantom.

In Vivo Imaging: The new camera system was used for prospective correction of head motion on nine volunteers: seven at 3 T and two at 7 T. Volunteers were instructed to stay as still as possible during MR imaging. The tracking target was either attached directly to the forehead or onto a mouthpiece. Tracking data were logged to file in all cases for later analysis.

Results and Discussion

The camera increases background RF noise by ~0.1% at both 3 T and 7 T, which is negligible. No structured noise was apparent (Fig. 2a). The camera slightly affects B0 homogeneity (Fig. 2b), but this can be largely corrected by reshimming. Tracking noise standard deviation during MR imaging is 1 µm, 12 µm and 1 µm in the scanner x, y and z-directions and better than 0.01 degrees in all three rotations. This represents a one to two order of magnitude improvement over existing systems and is sufficient for motion correction in extremely high-resolution MR imaging [7]. Drifts are negligible if the camera is left powered on, so as to maintain a constant temperature. No artifacts were visible in any in vivo scans acquired while using the camera (example image in Fig. 2c). Analysis of the images before and after correction is outside the scope of this abstract and will be published separately.

Figure 3 shows respiration and cardiac-related head motion in the head-feet direction, where it manifests itself most strongly. This is consistent with ballistocardiography literature [8], which reports head motion in the head-feet direction relating to the cardiac cycle. This effect is strongly apparent in our data for all subjects (example in Fig. 3), regardless of the marker fixation method. This indicates potential for cardiac/respiratory gating using motion data, which could be of interest at 7 T, where ECG gating is problematic.

Conclusion

In this work, we have developed an MR-compatible tracking system with sufficient precision to quantify respiration/cardiac-induced head motion. The system is highly suitable for use in prospective motion correction, but could have application whenever accurate position tracking is required during MRI.

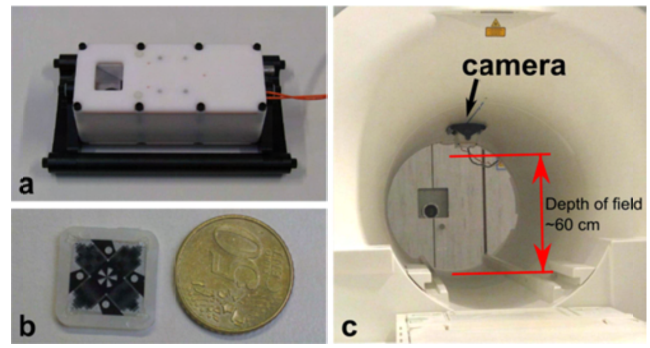

Fig. 1: (a) The MR-compatible camera developed in this work, (b) a 15 mm moiré phase tracking (MPT) target used for six degree-of-freedom head tracking and (c) installed in scanner.

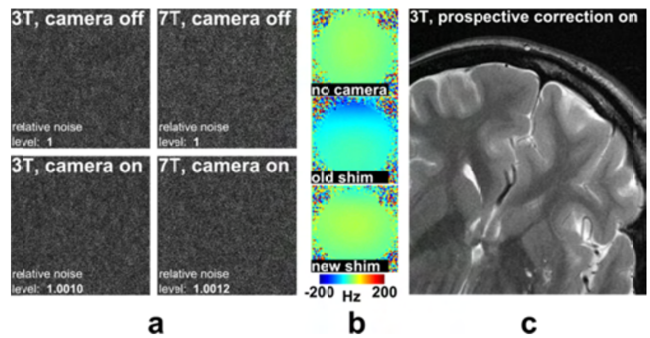

Fig. 2: MR-compatibility results: (a) RF noise tests at 3 T / 7 T; (b) field maps at 3 T; (c) a typical motion-corrected image (zoomed) obtained at 3 T (2D TSE, 12-channel coil, resolution: 0.4×0.4×3 mm, TR: 7000 ms, TE: 90 ms) during prospective correction, showing no artifacts from the camera system.

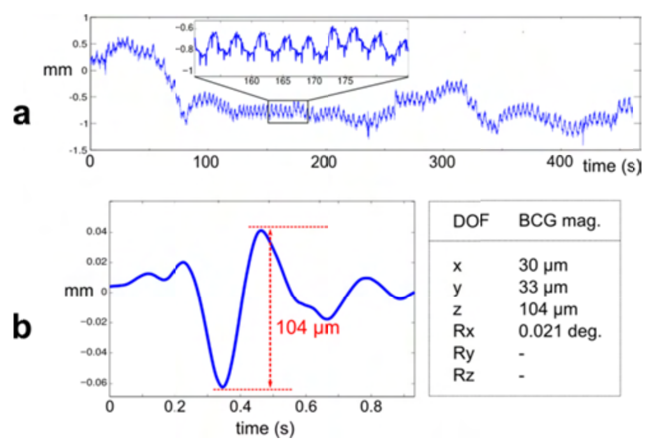

Fig. 3: Head tracking data showing subject motion in the head-feet direction during simultaneous MR imaging: (a) unfiltered data showing cardiac and respiratory components; (b) a ballistocardiogram formed by zero-phase filtering, peak detection, and then averaging repeating components in the original signal. Peak-to-peak displacement is 104 µm in the z-direction, but is smaller in other degrees of freedom (see table).

References

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