A method of prospective motion correction with reacquisition for effective diagnostic imaging of pediatric patients

W Scott Hoge[1], Onur Afacan[2], and Simon K. Warfield[2]
[1]*Radiology, Brigham and Women's Hospital, Boston, MA, United States,* [2]*Radiology, Boston Children's Hospital and Harvard Medical School, Boston, MA, United States*

Synopsis

This work presents a method for prospective motion correction with reacquisition developed for clinical pediatric imaging. A modified 3D MPRAGE sequence enabled prospective field-of-view steering and the recording of motion events from an electromagnetic (EM) tracking device. Software was developed to co-ordinate location measurements from the EM tracker, and report ``motion free'' time periods to the sequence, from which data reacquisition needs could be determined. Data from both healthy subjects and pediatric patients is presented, which demonstrates that dynamic, prospective FOV steering and real-time data reacquisition is an effective diagnostic imaging strategy for pediatric patients.

Introduction

Physical constraints in MRI data acquisition necessitate a relatively long scan time for certain scans, including high-spatial-resolution 3D imaging. Long acquisition times risk image quality degradation due to subject motion[1]. Several different motion sensors and motion compensation solutions have been proposed, including spiral navigators[2], volume navigators[3], camera systems[4], field probes[5], and EM tracking devices[6]. While many promising improvements in image quality have been achieved, none have yet been demonstrated to be effective in clinical diagnostic imaging of pediatric patients who may exhibit a large range of frequent motion. Frequent motion leads to the loss of k-space data due to encoding errors, and large magnitude motions create difficulties for strategies that require line of sight to markers or facial features. Consequently, we employed here an EM tracker and developed software to measure subject position during imaging, steer the field-of-view (FOV) to the current position, detect data samples corrupted by motion, and reacquire good data to replace motion-corrupted data. Results below demonstrate this strategy is effective in creating diagnostic quality images, in both volunteers undergoing predetermined motion patterns and in pediatric subjects.

Methods

All data was collected on a Siemens (Erlangen, Germany) 3T Trio system, equipped with a 32-channel receive head coil. A 3D MPRAGE sequence was modified to receive current position updates from an EndoScout (Robin Medical, Baltimore, MD) EM tracker[7], and steer the FOV in real-time. This required the addition of EM tracker gradients before each RF excitation pulse, but did not impact the acquisition time. A custom communications server (CommServ) was developed in C++ to co-ordinate data communication between the EM tracker and the sequence. A simple GUI written in Tcl/Tk and Expect, Fig. 1, enabled control of the CommServ by MRI Technicians. Communication was performed over TCP/IP via the open-source ACE socket library[8]. At each TR, the current EM tracker position was recorded by the CommServ, and a new FOV position was computed and transmitted to the sequence. Simultaneously, the new location was compared to the previous location, and if the displacement or deflection exceeded set thresholds (here: 1mm displacement; 1 degree deflection) the current time was marked 'motion present'. Periodically, every 10 TRs, the sequence would request records of 'motion free periods', from which reacquisition needs could be determined.
Because of the asynchronous nature of TCP/IP communication between the three computer systems (Scanner, Tracker, and CommServ), the data reacquisition followed the following time-stamp strategy to record and report motion-free periods. The first EM tracker gradient readout was marked 'init', and all subsequent events were measured from this initial event. During sequence preparation, a list of all needed k-space locations was determined and stored in a look-up table within the sequence. With each excitation, a time stamp for each location was recorded in the table. Every 10 TRs, the sequence would receive a list of previous motion-free periods (MFP) from the CommServ. The sequence then compared the recorded time stamps in the look-up table to the reported motion free periods, and marked any that fell between the period boundaries as 'motion free'. After the first prescribed volume, the sequence acquisition list was then re-ordered to only acquire those k-space locations that were not yet marked 'motion free'. The sequence would then terminate when either a) all of the prescribed acquisition locations were marked motion free, or b) the maximum specified number of volumes had been executed.
High resolution 1mm-isotropic 3D MPRAGE (TR=1500ms, TE=2.19ms, FOV= 260x260x176 mm, R=2) data was collected from 12 subjects, including 9 pediatric patients, with informed consent under IRB guidance.

Results

Figure 2 shows data collected from a healthy adult. The EM sensor position over time is shown in Fig. 2(a), with motion free periods shown by light gray bands. The elapse time for each acquired k-space location is shown in Fig. 2(b), where different colors indicate the number of times each location was acquired. The resulting reconstruction is shown in Fig. 2(c), with the first acquired volume shown on the left. The volume reconstructed from data incorporating reacquired data 0shows a dramatic reduction in motion-related artifacts, and much higher anatomical feature fidelity. Figure 3 shows similar data from a pediatric volunteer. Despite instructions to keep still, some movement did occur resulting in the degraded image on the left of Figure 3(c). Note this movement occurred during the acquisition of lines used for GRAPPA [9] calibration, indicated by a circle in the region with white background just past the 10,000 ms mark. By replacing motion-corrupted lines with reacquired motion-free data, however, many of the motion related artifacts were reduced, as seen at right in Fig. 3(c).

Conclusion

The results demonstrate that dynamic, prospective FOV steering and real-time data reacquisition is an effective strategy to overcome sampling errors from subject motion during MRI structural exams. In each case, the prospectively steered and reacquired data was comparable or significantly improved compared to the first volume of data—which included prospective FOV steering, but no data reacquisition. We demonstrated that this strategy is effective in creating diagnostic quality images, in both directed volunteers and in pediatric subjects. Open source versions of the CommServ software and user interface is available by request.

Acknowledgements

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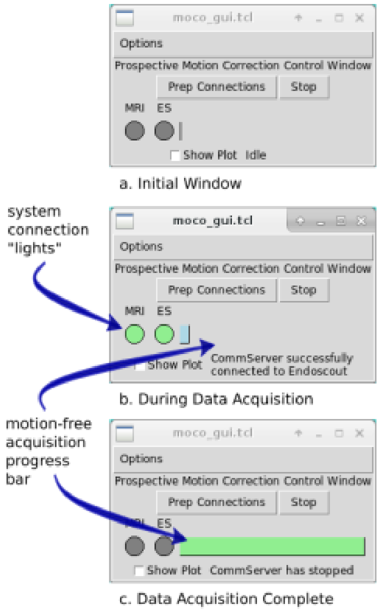
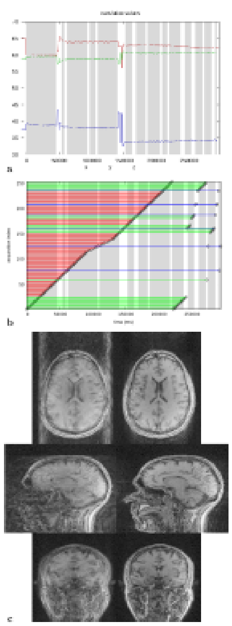
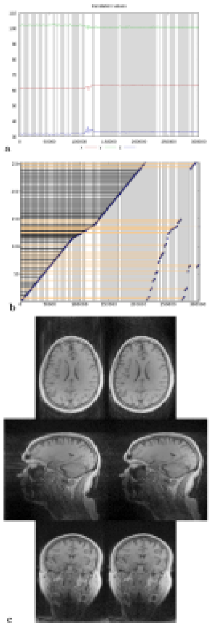
Figures



Graphical User Interface for the prospective motion correction software. The initial window (a) consists of two buttons for interaction, and components to display scan status. Indicator "lights" (b) show successful connections between the CommServ and the othersystems. Reacquisition progress is shown by a dynamic bar (c) that turns green once a complete set of motion-free data has been acquired.



3D MPRAGE images from a healthy volunteer at 3T using prospective FOV steering and reacquisition. a) motion record, b) k-space location acquisition history, c) motion-corrupted vs. motion-corrected images.



3D MPRAGE images from a pediatric patient at 3T using prospective FOV steering and reacquisition. a) motion record, b) k-space location acquisition history, c) motion-corrupted vs. motion-corrected images.