A rapid and robust method for reducing out-of-plane motion in dynamic imaging. Application to MRI thermometry on abdominal organs.

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Introduction

Several biomedical applications require the analysis of MRI signal changes in time, such as perfusion imaging (magnitude intensity changes related to contrast agent injection) or MRI thermometry (phase changes related to the Proton Resonant Frequency shift with temperature) for guidance of non invasive thermotherapy. Due to acquisition constraints and the presence of motion (breathing and cardiac activity), 2D rapid imaging is usually performed and the organ displacements in each image of the time series are registered to compensate for residual in plane motion. However, this strategy requires that most of the motion is included into the imaging slice, without out-of-plane motion. In this work, we propose a method to account for this problem by determining the main direction of motion in 3D based on the temporal analysis of motion oberved in two orthogonal slices during free breathing in liver and kidney. The gain in the precision of thermometry after reduction of out-of-plane motion is evaluated ex vivo and in vivo in volunteers and patients. In addition, this method allows for a rapid determination of the 3D trajectory of the target.

Materials and methods

All images were acquired on a 1.5 T Achieva scanner (Philips Healthcare, Best, The Netherlands) with a 4 elements phased array coil. In order to determine the main direction of motion, a set of 200 images were acquired during motion with two interleaved orthogonal slices (one coronal and one sagittal) centered on the region of interest, with the read out direction aligned with the head-feet direction. True-fisp images were acquired during 40 seconds with the following parameters: FOV=400 mm, matrix=128*109, TE/TR=1.2/2.43 ms, 60° flip angle, 6 mm slice thickness. Data processing was performed with in house developped code written in IDL and C++, and included the following steps : **first**, for each image in the time series, a large region of interest (ROI) was selected (covering the entire amplitude of displacement of the target) and the calculation of the apparent in plane motion relative to the first two orthogonal images were performed with the optical flow algorithm [5]. **Second**, a principal component analysis (PCA) was performed for the resulting sets of displacement vectors to obtain a basis of displacement vectors within the selected ROI. **Third**, the angles around the anterior-posterior (AP) and left-right (LR) directions were calculated using the basis vector from the PCA corresponding the the highest eigen value, in a smaller ROI surrounding the target location to correct the orientations of the two orthogonal slices. The complete process, including data acquisition and image processing, was less than 2 minutes in duration, and was iterated until the resulting correction angles were lower than 5°. At this step, the trajectory of the selected target was computed by calculating the coefficients to apply to the basis vectors derived from the PCA using a Levenberg-Marquardt fitting routine. For each set of orientations, MR thermometry was performed by acquiring echo planar images (EPI) with the following parameters : FOV=300 mm, matrix=96*96, TE/TR=18/72 ms, 67 lines/TR, Sense factor=1.4, 5 slices (4 coronal et 1 sagittal), 30° Flip angle. The in plane motion registration was performed with the already proposed multibaseline atlas method [3] to compute the motion corrected temperature maps and to calculate the standard deviation of the temperature in the selected ROI. This method was tested ex vivo on a bovine kidney positioned on a mobile platform which motion was aligned with the B_0 of the MRI (no angles around AP and LR directions). Several initial angles around AP and LR were tested and the number of iterations required to retrieve the correct angles (with less than 5°) were recorded. Then, this method was tested in vivo in volunteers (N=6) and patients (N=3).

Results

The ex vivo experiments showed that 2 iterations at maximum were required to retrieve the direction of motion and that the resulting errors in angle determination were less than 5° for both rotations around AP and LR directions (initial angles around AP/LR = 10/0, 10/10, 30/0, 45/45°). Figure 1 shows a typical example, obtained for the kidney of a volunteer, with orthogonal images (grey levels) and the proposed angulation corrections (red dashed lines) around the LR and AP directions, respectively. The second iteration resulted in correction angles lower than 5° for both directions (not shown). Figure 2 compares the standard deviation of the thermometry before and after correction of the angulation of the imaging slices on the kidney. The precision of the temperature estimate was improved by reduction of the out-of-plane motion with the proposed technique, since most of the pixels within the kidney have a standard deviation lower than 1°C (see Figure 2, image on the right). Figure 3 shows the trajectory of a selected target within the liver. As expected, motion is mainly along the Head-Feet direction (blue line). With the proposed approach, the standard deviation of the thermometry was significantly improved in 76% of the cases. All cases where no significant improvement of the standard deviation of the thermometry was observed correspond to minimal orientation changes of the imaging slices, for which the standard deviation of the thermometry was already low.

Discussion

The proposed method allowed for a precise and robust 3D determination of the angulation corresponding to the main axis of motion of a target in the kidney and liver. The reduction of out-of-plane motion allowed for improvement of the precision of the MR thermometry *ex vivo* and *in vivo* on volunteers and patients. The cost in acquisition duration remained acceptable (2 minutes extra time per iteration, including acquisition and processing) in view of the total duration of the current MRgHIFU treatments in abdominal organs [6]. The trajectory of the target can also be determined in 3D with the same data sets and much faster than already published methods [7,8]. Therefore, this information can also be directly included during the planning of the MRgHIFU therapy in order to integrate the motion of the tumour in the treatment strategy.

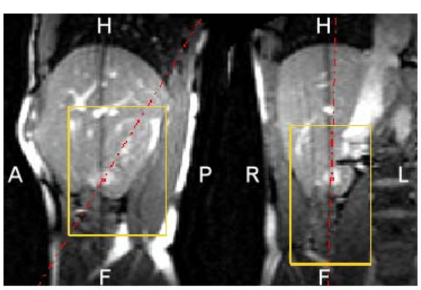

Figure 1 : Orthogonal slices acquired on the kidney, with the ROI for PCA calculation (yellow rectangle) and the proposed angle corresponding to the principal direction of motion (red dashed lines).

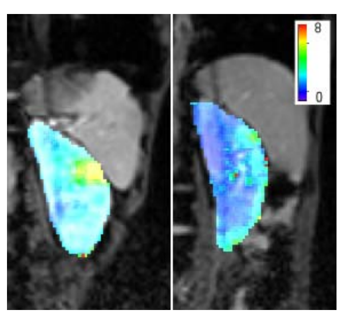

Figure 2 : temperature standard deviation images (in color) before (left) and after (right) correction of the slice angulation with the proposed technique.

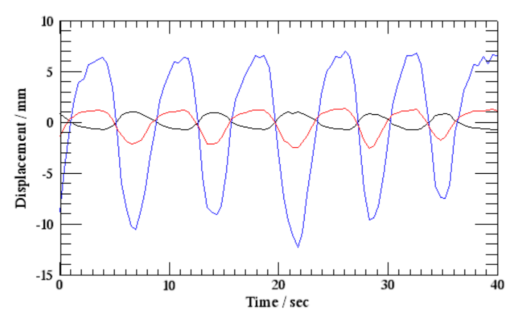

Figure 3 : orthogonal projections of the trajectory of the target along the Head-Feet (blue), Left-Right (red) and Anterior-Posterior (black) directions.

References

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