Motion Tracking by Constrained Reconstruction of Orthogonal Projections

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Introduction

3D reconstruction of interleaved orthogonal-projections was developed for time-resolved 3D MR angiography (1). Each 3D data set is reconstructed from two orthogonal projections by the AUCTION algorithm (Assignment and Update with CorrelaTION). Correlations with a 3D spatial constraint are used in each step of data assignment to solve the ambiguity problems in the original assignment and update algorithm, which was developed in the 1970s for biplane X-ray (2). The 3D spatial constraint is formed by combining all the rotational projections acquired during the first pass of the contrast agent (e.g. 64 projections are acquired as rotated biplane projection pairs over 32 seconds to cover the 3D K-space). Therefore, the 3D spatial constraint is an averaged approximation of the object. If the object moves during the data acquisition process, due for instance to the respiratory motion of renal arteries, the data set forming the spatial constraint will be blurred. The mis-registration of the 3D spatial constraint to a particular pair of orthogonal projections may introduce ambiguities in the AUCTION reconstruction. In this work, the robustness of the AUCTION algorithm in the presence of motion is investigated. The effectiveness of motion tracking by this technique is demonstrated in phantom studies.

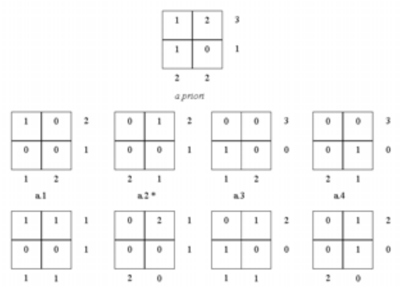
Methods

An illustration of the AUCTION algorithm is shown in Fig 1. The correlation analysis with a spatial constraint greatly reduced the ambiguity in the reconstruction. In the presence of motion, the orthogonal projections need to be aligned to the spatial constraint before the reconstruction. A simulation was done to illustrate the motion correction method (Fig 2). Assume a 'Y' shaped object moved around during the acquisition of the interleaved orthogonal projection. Therefore, the averaged spatial constraint is blurred. To align the pair of projections to the average position of the spatial constraint, the orthogonal projections are back-projected to form a low-resolution image, and correlation with the spatial constraint is performed to correct for the motion. This can be considered similar to PROPELLER MRI (3). After the alignment, the cross-sectional image is reconstructed from the pair of projections by the AUCTION algorithm.

A phantom study was performed to demonstrate the motion tracking capability. A syringe was filled with Gd (Omniscan). Periodic motion was induced manually. The motion is significant in an elliptical centric-order 3D sequence as shown in Fig 3b. To temporally resolve the motion, interleaved orthogonal projections were acquired by a modified 2D fast SPGR sequence (GE 1.5T Excite), head coil, FOV=20x20cm, 256x128 matrix, slice thickness 200mm, TR=3.5ms, flip angle=20°, BW 62.5KHz, ~0.5 s/frame. In total 64 projections were collected over 32 s. The 64 projections were combined to form the 3D spatial constraint. Motion was corrected by the method shown in Fig 2 and 32 3D data sets were reconstructed to track the motion at each second.

Results

In the simulation, the 'Y' shaped object was reconstructed accurately after the motion alignment, despite the blurred spatial constraint. In the phantom study, the different positions of the syringe at every second were resolved by reconstructing the corresponding pair of orthogonal projections (Fig 3 f-h).



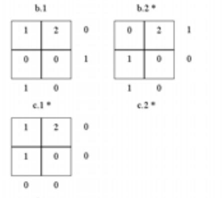


Figure 1. Illustration of the AUCTION algorithm. The original 2-by-2 image is illustrated in the first row as the spatial constraint data. The numbers in the image are the gray-scale values of the corresponding pixels. Two orthogonal projections are displayed below and to the right of the original image. In each step, the algorithm assigns one step-value to one pixel, and updates the corresponding values in the projections. In this example, the step value is 1 unit. In the first step, there are 4 potential positions to assign the value (a.1-a.4). By calculating the 2D correlation coefficients between the a priori data and the 4 potential solutions, a.2 is picked as the most likely solution. Similarly, in the second step, the pixel value is assigned to b.2, which has the highest correlation coefficient. In b.2, since one row/column sum value has already been updated to 0, there are only 2 potential positions to assign the 3rd pixel value as shown in c.1 and c.2. The correlation coefficients of c.1 and c.2 with the a priori data are actually equal, therefore we randomly pick one of them and assign the last pixel value to reach the final solution d.1.

Discussions and Conclusion

With a blurred spatial constraint, AUCTION algorithm still works as long as the orthogonal projections are aligned to the averaged position, which has a higher energy distribution. The spatial constraint is used as a soft constraint by correlation analyses in the AUCTION algorithm; therefore the blur is not transferred to the reconstructed images.

The motion is assumed to be rigid body motion (translation and rotation). Deformation will bring ambiguities to the AUCTION reconstruction, whose effects will be in investigated in the future.

In conclusion, by the AUCTION algorithm, 3D data sets can be reconstructed from two orthogonal projections, even in the presence of motion. In fact, due to its high temporal resolution, it potentially can be used to track gross motions, such as the respiratory motion in renal MRA.

References

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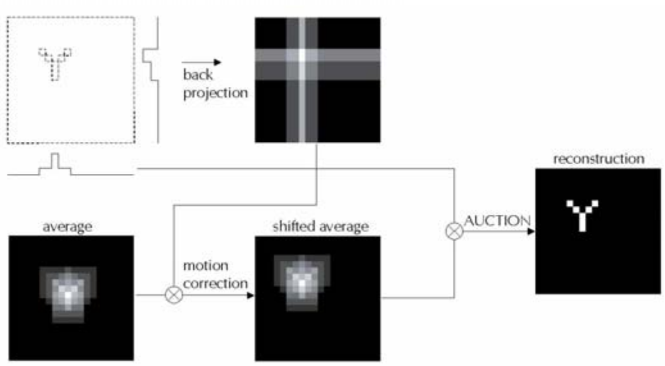

Figure 2. Simulation of the reconstruction of orthogonal projections after motion correction. The orthogonal projections are back projected to form a low resolution template image, which is correlated to the blurred spatial constraint formed by combining all the projections. The translational and rotational motions are then corrected for the blurred average so that the orthogonal projections are aligned to the spatial constraint. The image is then reconstructed by the AUCTION algorithm.

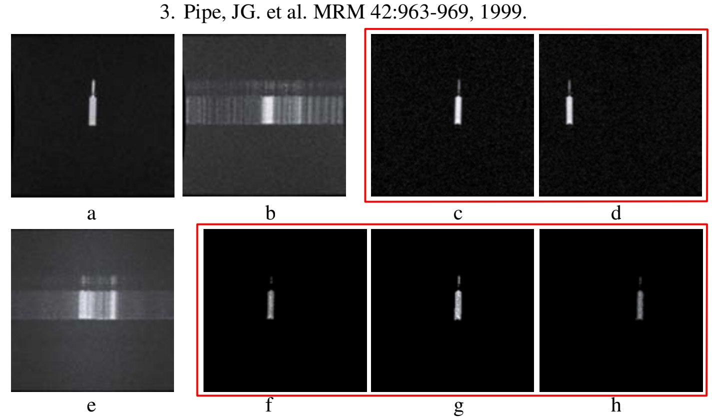

Figure 3. Phantom study shows motion tracking by AUCTION reconstruction of orthogonal projections. All the images are coronal MIPs of 3D data sets. Image a shows the phantom (a syringe filled with Gd) without motion. Image b shows the motion-corrupted data acquired by elliptical centric-ordered 3D SPGR sequence. The motion is periodic over 30s. Images c and d are a pair of orthogonal projections acquired in one second. No significant motion is considered to exist during the 1s acquisition. 32 pairs of orthogonal projections were acquired over 32 seconds. By combining all the 64 projections, a blurred 3D data set (e) is used as the spatial constraint for the AUCTION reconstruction with motion correction. Image f-h are three reconstructed 3D data sets to show the different positions of the phantom at three different time points.