MRI INTER-PACKET MOVEMENT CORRECTION FOR IMAGES ACQUIRED WITH NON-COMPLEMENTARY DATA

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ABSTRACT

Movement during the acquisition of magnetic resonance images can cause artifacts that interfere with subsequent image analysis. In this paper we address the problem of inter-packet motion and provide a method to minimize errors associated with this artifact. The procedure is based on an iterative packet-to-volume registration process and does not require complementary information such as multi-modal acquisitions or protocols that provide redundant volume data. A Kaiser-Bessel function is used to interpolate missing data. Experiments with simulated data demonstrate that the packet-to-volume registration improves greatly after a single iteration and maintains improvement for the following iterations, while experiments with real data demonstrate a substantial reduction in associated artifacts and improvement in quality. In both cases anatomical integrity is preserved after reconstruction.

***Index Terms*—** Image Reconstruction, Image motion Analysis, Motion Compensation, Image Registration, Magnetic Resonance Imaging

1. INTRODUCTION

Magnetic resonance imaging (MRI) provides exquisite visualization of the soft tissue structures of the brain and has become central to non-invasive studies of neuro-anatomy and the diagnosis and management of neurological disorders. The use of MRI for this purpose can be limited by artifacts, the most prominent of which is due to motion artifacts during image acquisition[1]. Motion artifacts are generally classified as either: intra-packet movement (misalignment between 2 or more slices within a packet and/or movement within a slice), inter-packet movement (misalignment between two or more packets), or a combination of both. In this paper we present an image post-processing method that can correct for inter-packet movement. We define a packet as a multi-slice, single shot, acquisition[2]. Each set of slices acquired during a single readout is considered to be a packet.

Several methods have been proposed to correct for movement artifacts[1-11]. Mechanical restriction of head motion is generally insufficient for controlling small movements[3]. Prospective methods to correct for inter-packet motion have been proposed but require additional data to be acquired with the image data (e.g. navigator echoes, PROPELLER data) and thus are not applicable to retrospective analysis of data that does not include this extra information[4, 11]. Ahmed *et al.*[1] have described a k-space retrospective method that suppresses both intra- and inter-packet motion artifacts, but the procedure is dependant on the implementation of a newly proposed MRI acquisition sequence. Such a solution limits the applicability to images acquired with this particular sequence. Another retrospective procedure has been proposed by Rousseau *et al*.[9]. The method was applied to fetal brain MR images and requires multi-plane (coronal, sagittal, and transverse) acquisitions to provide complementary information. Accordingly, the method is restricted to images with such redundant data.

In this paper, we present an image-driven retrospective method to correct for artifacts attributed solely to inter-packet motion. In addition, a Kaiser-Bessel (KB) function is used to interpolate missing data points during the reconstruction process. A Euclidean distance algorithm is incorporated to determine the optimal interpolation radius for the KB function. Our goal was to develop a method to correct for inter-packet motion using only the volume data itself, without any other complementary acquisitions

2. MATERIALS AND METHODS

The features of our proposed method are:

1. The imaging protocol consists of a single-plane acquisition and does not require multi-plane scans like the method proposed by Rousseau *et al.* From a retrospective point of view, this gives the method a broader range of MR image applicability.
2. Packet-to-volume registration is used as opposed to slice-to-volume. This takes advantage of the constraint that multiple slices within a packet are aligned and provides more data points for the correction procedure.
3. Volume reconstruction is performed using a KB interpolation function.

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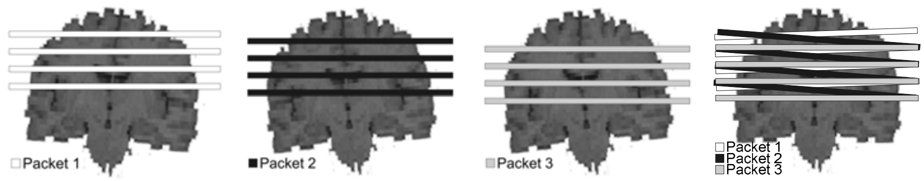

Fig. 1. Packet 1 is acquired with the brain initially rotated slightly in the clockwise direction (left), packet 2 is acquired with a larger rotation in the counter-clockwise direction (middle left), and packet 3 is acquired after the brain undergoes a small translation in the axial direction (middle right). The image on the right shows the result of registering all packets together. Notice the missing data (areas where the packets do not cover the image) resulting from motion.

2.1. Inter-Packet Reconstruction Algorithm

The procedure for inter-packet motion correction starts by creating an initial registration target, and then iterates to refine the registration of each packet to this target as described below.

Initialization:

1. Extract packets 1..*n* from the image affected with motion
2. Blur packets 1..*n* in the slice direction to fill the slice gaps resulting from the extraction process
3. Register packets 2..*n* to packet 1 using a cross-correlation objective function and rigid body transform (although packet 1 is used as the reference packet, any packet can be used as a reference without affecting the results of the inter-packet correction procedure)
4. Using a KB interpolation function, reconstruct a 1mm isotropic volume from the *n* registered packets (initial target image)

For iter=1 to 10,

5. Register packets 1..*n* to the isotropic target image
6. Create a new target image by reconstructing a 1mm isotropic volume from *n* packets (KB interpolation function)

Registration is performed using a rigid body transformation consisting of only rotations and translations (6 degrees of freedom (DOF)). The similarity index used is the cross-correlation coefficient. This index is preferred since we are not registering across modalities.

Volume reconstruction is done using a splatting [12] approach that based on an non-isotropic KB function. Each of the *n* registered packet volumes are considered as a set of samples that contribute to the overall reconstructed volume. Each voxel within each packet is interpolated into the reconstructed volume using a KB function with position defined by the registered packet, and a spatial extent defined by the optimized interpolation radius. Therefore, each voxel from each packet has a weighted effect on its surrounding neighbors and the range defined by the calculated radius ensures that all missing data points have been estimated. Finally, each of the *n* packets spreads their contribution to the resulting reconstructed volume.

3. EXPERIMENTS

The inter-packet movement correction procedure was applied to both simulated data and real data. MR scans of the head were obtained from subjects with Multiple Sclerosis (MS) at our institute. Each subject provided informed consent and the study was approved by the institute's research ethics committee.

3.1. Simulated Movement

Thirty images with simulated movement artifacts were created using a method that yielded volumes similar to real scans affected with inter-packet motion. Induced movement artifacts were limited to rotations and translations (6 DOF) using one transform per packet.

Each image with synthesized movement was derived from a manually selected T1-weighted MR image (35ms/9ms/30˚/250mm TR/TE/FLIP/FOV) with no visual movement artifacts. A transformation file was used to create movement artifacts. Each file simulated movement through the selection of three transformation sets (one for each packet) composed of 6 transformation vectors (3 rotations and 3 translations) ranging from 0° to 9° for rotations and 0mm to 20mm for translations. The 30 images with varying degrees of motion were simulated using the procedure described below.

Procedure:

1. Start with an MR image with no visually perceived inter-packet motion
2. Apply the first transformation matrix in the transformation file to the whole image
3. Extract packet 1 from the transformed image using an in-house extraction software
4. Repeat steps 2 and 3 for the remaining 2 packets using the second and third transformation matrices respectively
5. Combine packets (with no registration) to produce an image with inter-packet motion

Each packet extracted in step 3 obtained after simulated motion will resemble the packet data within the images on

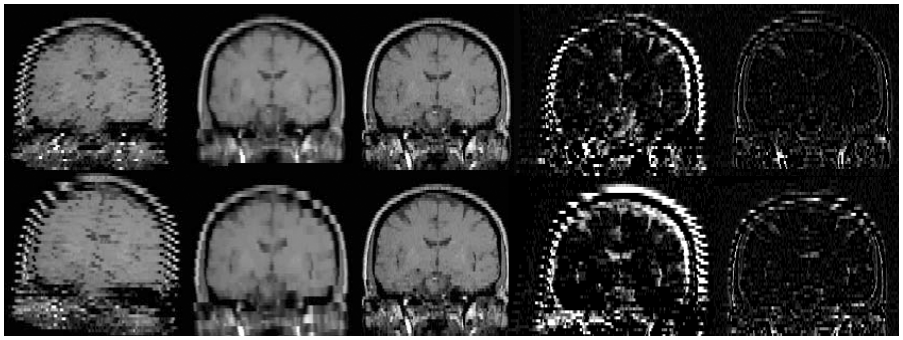

Fig. 2. All the images are from simulations of the same subject. Images with moderate (*top left*) and extreme (*bottom left*) motion artifacts were created using the procedure described in section 3.1. The 2nd column of images shows the results of the reconstruction process. The 3rd column is the original image. The 4th column shows the difference maps between the images affected by inter-packet motion (1st column) and the originals (3rd column). The 5th column shows the difference maps between the corrected images (2nd column) and the originals (3rd column).

the left (packet 1), middle left (packet 2), and middle right (packet 3) side of Fig. 1. Additionally, the combined image in step 5 will resemble the data contained within the packets on the left side image of Fig. 2.

Each of the 30 simulated images was corrected using the inter-packet reconstruction algorithm described in section 2. The resulting image (reconstructed) was registered against the original image using a cross-correlation coefficient as the similarity index. For each image there were 11 correlation values produced (correlation value between the image with simulated motion and the original image + 10 iterations).

3.2. Real Data

The reconstruction algorithm was also performed on data that contained real inter-packet motion artifacts. These data were obtained from 10 patients undergoing treatment for MS. After image correction, the volume of each corrected image was compared against either a previous or following timepoint using the cross-corrrelation coefficient.

4. RESULTS

4.1. Simulated Movement

Figure 2 shows the pre-/post- reconstruction, original MR, and pre-/post- reconstruction difference maps images for two degrees of motion: moderate (translation: 0-3mm, rotation: 0°-3°) and severe (translation: 3-9mm, rotation: 3°-9°).

The top half of the image shows the moderate case, while the bottom half demonstrates the severe case. The results before and after the reconstruction process are shown in columns 1 and 2 respectively. The correction produces a vast improvement, as shown by the reduction in the difference maps (columns 4 and 5). More importantly, the reconstructed images strongly resemble the originals (column 3). Similar results were observed for the other 30 images.

Figure 3 shows the average correlation between the original and reconstructed images as the number of iterations increase. We can see that reconstruction results improve greatly after the first iteration and change very little subsequently.

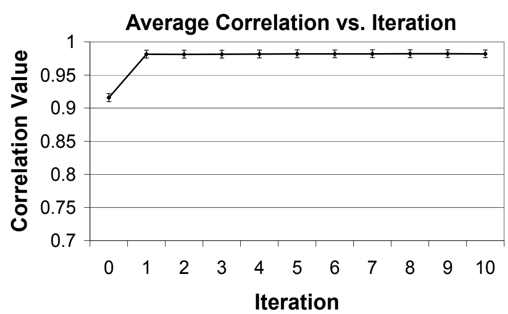

Fig. 3. Average correlation values (with standard error bars) at each iteration of the reconstruction process (*iteration 0 is the image with simulated motion*) of the 30 images with motion.

4.2. Real Data Cases

Figure 4 show the outcome of applying the reconstruction algorithm to real data. We can see that there has been a substantial reduction of movement artifact between the pre- and post- reconstructed images. Similar results were seen with the six other reconstructed images.

5. DISCUSSION

We have presented a method for reconstructing images affected by inter-packet movement using data from only a single-plane MR acquisition. This technique does not

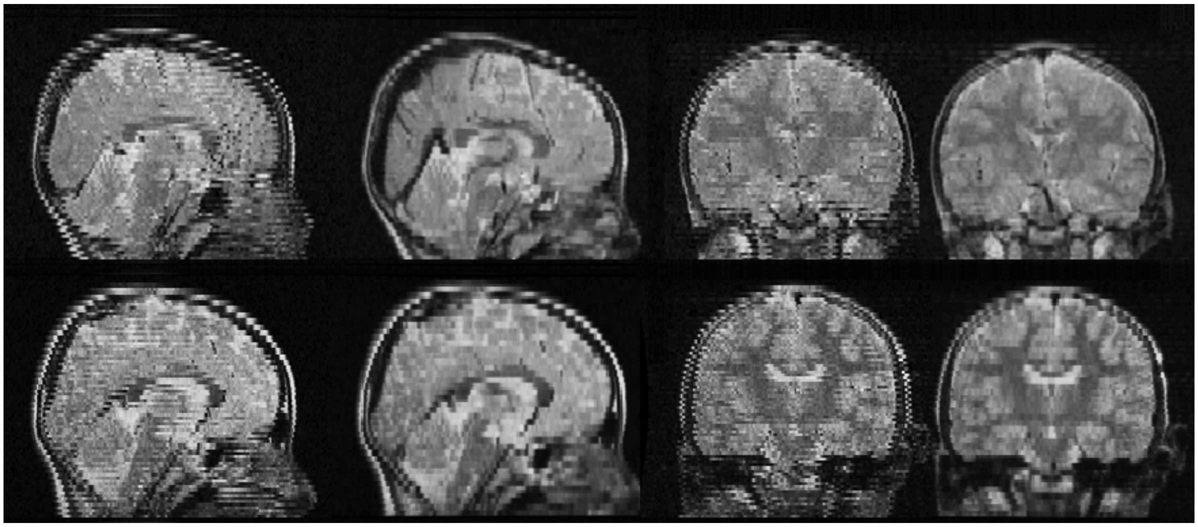

Fig. 4. Mild (top) and extreme (bottom) motion artifacts which were corrected using the previously described algorithm. Sagittal view of image with motion artifacts (*left*), sagittal view of the reconstructed image (*middle left*), coronal view of the image with motion artifact (*middle right*), and coronal view of the reconstructed image (*right).*

need other data in a complementary plane of acquisition. Interpolation was achieved using a KB function. The procedure was applied to 30 brain images with simulated inter-packet movement and 10 brains with real inter-packet movement. In the simulated cases, the average correlation value improved from 91.6% to 98.1% between the original and reconstructed data after the first iteration; demonstrating that the method is robust and accurate. Visual inspection by expert readers of the original and reconstructed images corroborated the preservation of anatomical integrity and packet alignment. In the case of the real data analysis, the reconstructed images corrected the movement artifacts in the original data. Therefore, we can conclude that the method works with real data.

It should be noted that when interpolation is performed to determine missing data points, as in this method, larger structures tend to be less affected than smaller structures. As the volume of missing data points due to motion increases, the ability to preserve anatomical integrity decreases. As such, a threshold for quality control can be determined based on the size of the structure of interest: e.g., lesion studies would require a smaller movement threshold than brain volume analyses.

The inter-packet reconstruction methodology has been validated on both simulated and real data. The proposed retrospective method is applicable to all multi-slice MR images and is not limited by a requirement for complementary resolution or protocol. It utilizes only the information contained within the acquired image to reconstruct a 3D volume. Further work could produce a metric that would quantify inter-packet movement allowing a fully automated procedure to detect inter-packet motion, correct the artifact, and assess the analyzability of the reconstructed image

6. REFERENCES

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