Rigid motion correction of PET and CT for PET/CT brain imaging

Matthew Bickell[1], Jung-Ha Kim[2], Ahmadreza Rezaei[1], Johan Nuyts[1], Roger Fulton[2]

***Abstract*—A rigid motion correction technique is applied to both PET and CT data from the Siemens mCT PET/CT scanner. Motion was applied to a Hoffman brain phantom during both the CT and PET scans, as well as between them. The motion data, which was tracked by an external motion tracker, was used to correct the motion corrupted tomographic data during reconstruction. The motion corrected CT reconstruction was used for attenuation correction in the PET reconstruction. The subsequent reconstructions are compared to scans taken without motion to show the effectiveness of the motion correction.**

I. Introduction

Motion during a CT or a PET scan can corrupt the data and significantly reduce the diagnostic value of the subsequent reconstructions. Such data sets often result in an additional scan being performed, possibly increasing the patient dose and scan time per patient. This is especially true for paediatric patients, where sedation or general anaesthesia is often used to avoid patient motion during the scan.

For brain imaging, the motion of the head can be corrected using rigid motion correction schemes, as has been demonstrated in both PET [1], [2] and, more recently, in CT [3]. Thus, it is now possible to incorporate motion correction into a PET/CT scan to correct both modalities and use the corrected CT for attenuation correction in the PET reconstruction. While solving the problem of motion during each scan, the problem of motion between the scans is simultaneously solved.

II. Method

The Siemens mCT PET/CT scanner (Siemens Medical Solutions Inc., Knoxville, TN, USA) was used to acquire scans of a Hoffman brain phantom. The motion of the phantom was tracked using six OptiTrack Flex-13 cameras (NaturalPoint Inc. Corvallis, OR, USA). The cameras emit infra-red light which reflects off small spheres attached to the object being tracked, which are then imaged by the cameras. The cameras can be easily set up in arbitrary locations (see figure 1), and, after a quick system calibration and marker registration, tracking can begin. The system reports 6 degrees-of-freedom at frequencies of up to 120 Hz.

A Hoffman brain phantom was filled with ^{18}F-FDG with an activity of 186 MBq. A calibration was performed to determine the transformation matrices from the OptiTrack coordinate system to the PET and CT coordinate systems as follows [4]: six stationary scans of the phantom were taken in various positions throughout the field-of-view in the PET and CT, using the OptiTrack system to record the pose at each position. The 30 relative transformations between each of these positions could then be determined from the recorded poses as well as from the reconstructions of these scans using image registration techniques. For each modality, using these two sets of 30 relative transformation matrices, the transformation matrix from OptiTrack coordinates to PET or CT coordinates could be determined. A reference marker, which is permanently attached to the scanner gantry, allows the calibration from one setup to be used to for another setup, thereby avoiding the need to perform a new calibration each time the cameras are moved.

[1]Department of Nuclear Medicine, KU Leuven, Belgium. [2]Brain & Mind Centre and the Faculty of Health Sciences, University of Sydney, and Department of Medical Physics, Westmead Hospital, Sydney, Australia.

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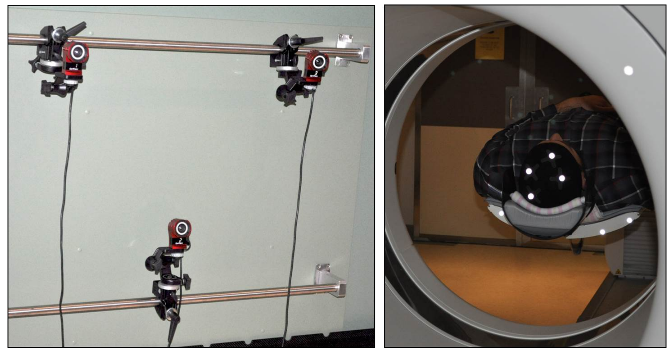

Fig. 1. Shown on the left are three of the six OptiTrack Flex-13 cameras set up for motion tracking, and on the right is an example of the tracking markers attached to a cap worn by a volunteer, lying on the patient bed of the scanner.

The phantom was then scanned in the CT scanner using a pitch of 0.8 and a scan time of 10.5 s, with a collimation of 64×0.6 mm. During the scan the phantom was made to roll on the bed. The phantom was then scanned by the PET scanner for 10 minutes, during which time it was manually moved throughout the scan. The data were acquired in 64-bit list-mode format. A stationary CT and PET scan were also acquired for reference. The CT data were reconstructed using the MLTR algorithm [5] while correcting each projection angle for motion during the reconstruction [3], [4]. The PET data, which included time of flight (TOF) information, were reconstructed using the TOF list-mode based ordered subsets expectation maximisation (OSEM) algorithm [6], [7], correcting each detected list-mode event for motion [1]. Resolution modelling was performed during the reconstruction using an image-based convolution [8] by a stationary Gaussian kernel

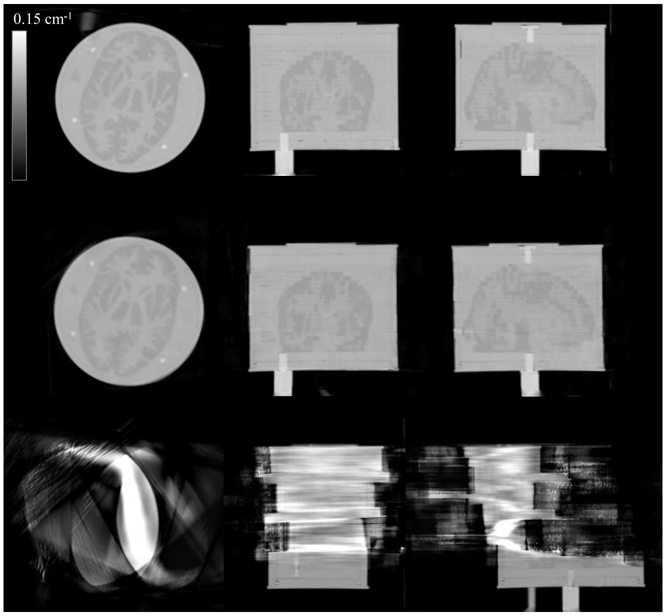

Fig. 2. The reconstruction of the stationary phantom is shown in the top row, with the motion corrected reconstruction of the moving phantom in the middle row, and the latter data reconstructed without motion correction in the bottom row. Residual motion artefacts can be seen in the motion corrected reconstruction, but much of the motion has been corrected for.

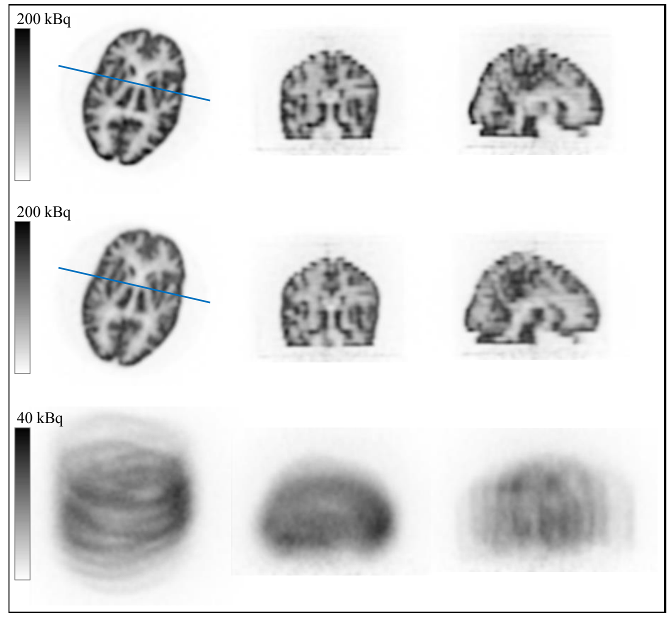

Fig. 3. The reconstruction of the stationary phantom is shown in the top row, with the motion corrected reconstruction of the moving phantom in the middle row, and the latter data reconstructed without motion correction in the bottom row. The blue lines indicate where the profiles shown in figure 4 are located.

with FWHM = 4.9 mm [9]. Both data sets were reconstructed to a single reference pose, which accounted for the offset between the scanners, and allowed the motion corrected CT to be used for attenuation correction in the PET reconstruction.

III. Results

The CT reconstructions are shown in figure 2 and the PET reconstructions in figure 3. The motion corrected CT reconstruction suffered from a uniform 4% scaling in comparison to the reference reconstruction. This has not been observed in previous CT motion correction studies we have performed and will be investigated further. The PET reconstructions were performed using either the attenuation map derived from the reference CT scan or the motion corrected CT scan. The profiles through these two reconstructions are shown in figure 4. The effect of the aforementioned scaling in the CT attenuation maps can be seen in these profiles since the two PET reconstructions match closely except for a slight scaling between them.

IV. Discussion

The reference pose in CT coordinates was converted to PET coordinates to align the attenuation image and the PET reconstruction. A small offset between the two images was observed in the transaxial direction. This was accounted for by doing an image registration between a preliminary PET reconstruction and the attenuation image. The cause of this offset is currently being investigated and could be due to slight movement of the motion tracking cameras; measures will be taken to avoid this in the future.

The PET reconstructions demonstrate that the motion corrected PET data and attenuation image produce results that

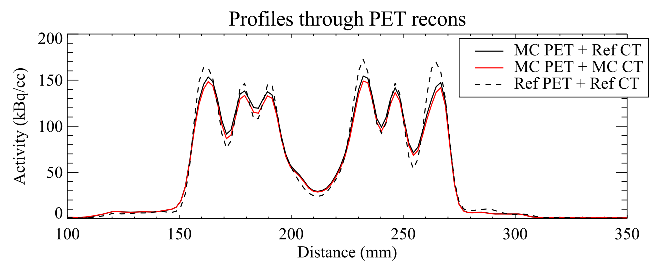

Fig. 4. Profiles through the PET reconstructions (as indicated in figure 3) of data without motion using the reference CT for attenuation correction (AC) (dotted curve), and PET reconstructions with motion correction using the reference CT for AC (black curve), and the motion correction CT for AC (red curve). Some resolution loss can be observed between the motion corrected and reference PET reconstructions. The motion corrected PET reconstructions using the motion corrected and reference CT for AC match closely.

are in good agreement with the reference data. The residual motion artefacts in the motion corrected CT image, which was used for attenuation correction, did not appear to affect the PET reconstruction. A slight loss of resolution was observed in the PET reconstruction due to imperfect motion estimation. This resolution loss was quantified as being equivalent to a smoothing of the reference reconstruction by a Gaussian kernel with a FWHM of 3.5 mm in all directions. This may be improved by better temporal synchronisation and spatial calibration between the OptiTrack and PET systems.

V. Conclusion

It has been demonstrated that motion correction techniques can be used to correct both PET and CT data which have been corrupted by motion, including motion between the scans. This could significantly improve clinical studies where patient motion is present during the PET or CT scan, and remove the risk of using a misaligned attenuation image for the PET reconstruction. This would remove the need for sedation or general anaesthesia in patients where motion is expected, for example in paediatric patients.

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