Effects of Head Movements Measured During PET Scans

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Abstract

We have measured the head movements of patients during PET scans, using two cameras fixed above the bed. The cameras observe motion of infra-red reflectors attached to a mouthpiece attached to the patient's upper jaw by a tooth splint. The entire assembly is completely rigid, both for patients with dentures and for patients with their own teeth. Most patients were able to tolerate the extra inconvenience of the mouthpiece, although some refused to try it.

The effects of head motion arise both in re-positioning the patient between scans (e.g. between a raclopride and a flourodopa scan) and during the scans. Typically we measure uptake over a 30-minute period for raclopride, and during 10-minute intervals for flourodopa. Patient repositioning errors of up to 7-10mm were observed between scans, and even during a short 10-minute scan, the patients may slip 7-10mm within their face masks. Experiences with measuring the motion are explored in the paper.

I. Introduction

We have measured the head movements of patients during PET scans, simultaneously with PET imaging, using two infra-red sensitive CCD video cameras fixed above the bed. The cameras observe motion of infra-red reflectors attached to a mouthpiece attached to the patient's upper jaw by a tooth splint, called a landmark device. Our objective was to create a rigid marker quickly, which could be used conveniently with all patients, to measure head movements during PET scans.

Other researchers are investigating patient motion data [1, 2, 3] but we believe that we are the first to obtain motion data simultaneously with the PET image data. With this data we are able to evaluate the effect of patient motion on the clinical results.

II. Methods

A. Manufacture of Landmark Device

A dental resident made a tooth splint within an hour of the patient's arrival at the PET suite, by first taking a maxillary impression with an irreversible hydrocolloid (fast-set alginate). He used a stock impression tray, taking around 5 minutes. He then poured up the impression with dikken stone, which took a further 30 minutes. Fabrication of a maxillary splint with light cured acrylic took around 20 minutes. The splint was therefore ready within an hour, which provided just enough time before the patient's attenuation scan was performed.

Initial attempts to make the splints quickly, using different materials, were not always successful, in that the splint did not always fit the patient's teeth (although the splint always fitted the impression well). Subsequent efforts were all successful, and a further refinement of wax rope around the edge of the splint, provided a yet more comfortable and secure fit. In all cases, the splint was very rigid, with no discernable movement whatsoever during the entire scanning period. The method works for patients with dentures, and for patients without. One patient had very worn teeth, probably from grinding his teeth, but this did not affect the fit of the splint. Most patients were able to tolerate the extra inconvenience of the mouthpiece, although some refused to try it.

The cameras sample the position of each of N markers in the x, y and z direction in the videometric coordinate system 30 times every second. The x direction is the horizontal axis, such that a "nod" is reflected by a rotation about the x axis. The y-axis is vertical, and the z-axis lies along the axis of the tomograph. We usually use 3 markers in a triangle, where each marker is a round infra-red reflecting dot of diameter 7 mm. The dots are attached to a lightweight rigid sheet of plastic, which is glued to a hollow rectangular plastic tube. The hollow tube fits exactly into a smaller, solid plastic rectangular tube which the dentist fixes into the tooth splint parallel to the upper jaw.

The acquired data is timestamped to allow for gaps such as arise when the nursing staff move in front of the cameras, or when the patient moves their hands.

B. Transformation of Motion Data

The raw motion data consisting of the 3D positions of the 3 reflective markers in the reference coordinate system K_v of the videometric system has to be processed to determine the 6 motion coordinates of the marker-head system in the PET coordinate system.

First, the 3D marker-head motion data are converted into the coordinate system of the PET scanner. We use a calibration box with several infra red reflective markers which is attached to the bed and may be moved to various positions within the PET scanner, to obtain a conversion for the videometric system into the PET coordinate system.

The 3D marker-head motion data are then transformed into the 6 motion coordinates (translation in the x, y and z directions, and rotation about the x, y and z axes), using an iterative fitting procedure based on the Levenberg-Marquardt Chi-Square minimisation algorithm [4]. Thus our software actually computes the motion in the x,y and z directions, and the rotation about the x, y and z axes with respect to the coordinates of the PET system [5]. The code is fast and even on a slow old IBM 386 computer we can process 3 samples per second. The measurement accuracy of this system is observed to be around 0.2mm within the calibrated working volume.

C. Correction of emission image data for Motion

After conversion of the motion data to the coordinates of the PET scanner, the data can be used to correct the acquired emission images for motion artifacts.

Ideally the image data is acquired in list mode, so that the lines of response (LOR) can be appropriately rebinned. We presented two methods for rebinning the LORs in [5], and another is presented in [6], which utilises a little-used feature of a Scanditronix PC-2048B PET scanner by which up to 8 possible rebinning positions may be used during an image acquisition. Unfortunately we cannot use any of these approaches with our CTI/Siemens ECAT 853 scanner, although list mode acquisition is a feature of the latest CTI/Siemens HRPLUS scanner.

Therefore we use our alternative method for deblurring the image data, based on postprocessing the image data by deconvolution of the image data with a so-called motion kernel, also described in [5].

III. Results and Discussion

A. Motion Data

Figure 1 shows motion of the marker-head system obtained during the first 12 minutes of a dopamine scan on a 52-year old patient with suspected Parkinsons disease.

Each box in the figure shows the motion of one marker in the x, y and z directions from the original position. Note that the scales for markers 2 and 3 differ from that of marker 1. This arose because markers 2 and 3 were interchanged about 40 seconds after the scan started because the patient moved, and the markers were labelled according to their vertical position, highest one first. During the slight motion, markers 2 and 3 which were nearly horizontal, became interchanged. Our software now corrects for this occurrence.

Also note the nurse was standing in front of the patient taking a blood sample after 10 minutes of the scan – our time-stamped software allows for this by interpolating the data between interrupted samples.

This has been translated into the 6-D motion of the marker-head system as shown in Figure 2.

Note that the data points do not all start at zero; indeed, the deviation in the z direction along the tomograph axis appears to start at 4 degrees and 10mm. This arises because for movement disorder research, we typically measure uptake of raclopride over a 30-minute period, followed by a 2-hour dynamic flourodopa scan consisting of 12 10-minute intervals. Data in Figure 1 and Figure 2 are based on the patient's initial position in the tomograph for the raclopride scan, showing that the patient was not repositioned in the same place for the later dopamine scan.

The motion data acquired for this patient during both the raclopride and dopamine scans separated by 50 minutes is visualised in Figure 3. The first 30 minutes is a raclopride scan and then a 2 hour flourodopa, of which the first 12 minutes is shown in Figures 1 and 2.

Figure 3 shows the absolute deviation of a point in the patient's head that was in the center of the PET coordinate system at the beginning of a first raclopride scan.

Although the nursing staff are confident that they can achieve a re-positioning accuracy of around 7mm measured from the end of one scan to the beginning of the next, the motion data show that the actual deviation is more than 10mm from the *start* of the raclopride scan, mainly due to the patient "nodding" *during* the raclopride scan, causing a displacement of around 4mm by the end of the raclopride scan. This was followed by mispositioning of around 6mm along the tomograph axis (the z-axis) at the start of the dopamine scan.

Note also that the mean displacement of the center point *during* the dopamine scan is 7mm (from 6mm to 13mm).

B. Image Correction

We used the motion kernel described in [5] to deconvolve the central 6 slices of the raclopride image obtained during the scan of the above patient, but the results are visually inconclusive, and it is difficult to assess the impact on the clinical statistics.

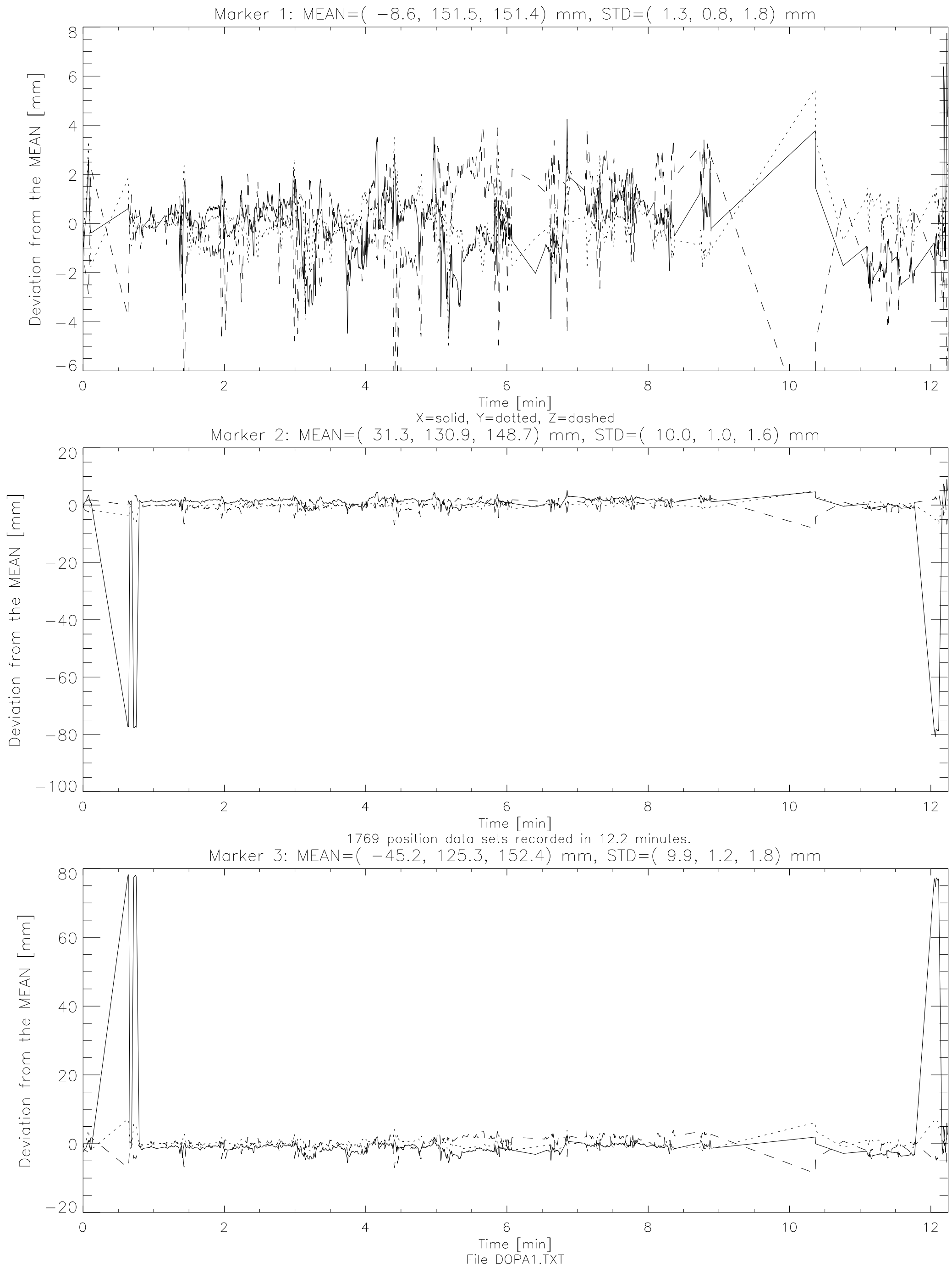

Figure 1: 3D motion of the three markers during the first 12 minutes of a dopamine scan on a suspected Parkinsonian patient

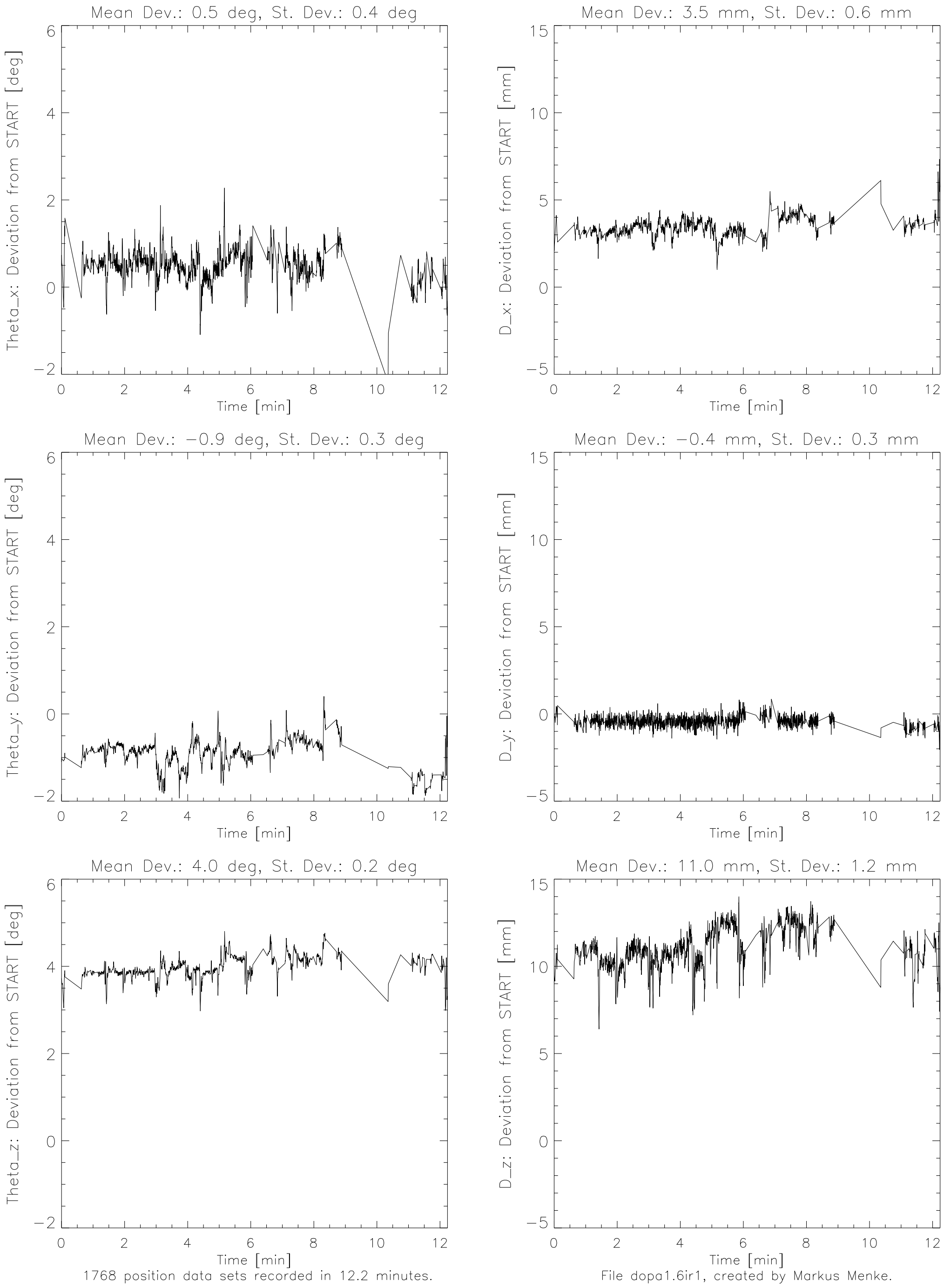

Figure 2: 6D representation of the 3D motion data shown in Figure 1

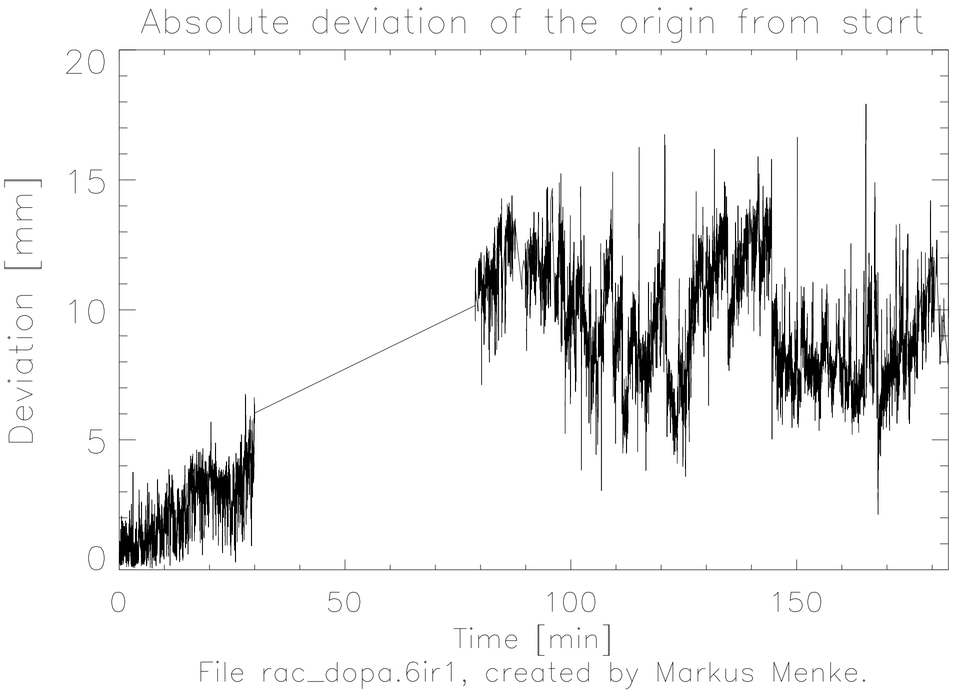

Figure 3: Absolute deviation of a point in the head from the center of the PET coordinates

IV. Conclusion and Future Work

We have described our technique for measuring patient motion during PET scans, using markers attached to a tooth splint attached to the patient's upper jaw. Although this is a relatively inconvenient measurement system, it is highly accurate and so may be used as a yardstick against which different measurement techniques may be judged. We have observed motion of up to 7-10mm of the patients within their masks during a scan, and repositioning errors of 7-10mm between scans. Ideally the measured motion data can be used to rebin the lines of response to compensate for motion blurring in the image. Alternatively we can apply our motion compensation methods [5] to deblur the images, although further work is needed to assess this method. We can also measure the effectiveness of alternative methods to hold the patients still.

Our future research will include exploring other methods of acquiring motion data, which do not involve using tooth splints.

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