Event-by-Event Attenuation Measurement for ACS2-Based PET Systems

Jens Langner, Hagen Mölle, Sören Dittrich, Edmund Will, Jörg van den Hoff

***Abstract*—Patient motion during acquisition is known to produce severe image artefacts and to limit the image quality in PET. Moreover, it affects exact quantification of tracer kinetic transport processes. To overcome these limitations, different motion correction methods have already been introduced in the past. They either allow for realigning the images of the individual frames of a dynamic PET study via spatial transformations [1] or for realigning each single coincidence event of a list-mode data stream prior to image reconstruction [2]. In both cases, however, patient motion is only compensated during the emission phase of a PET acquisition. This is the case because PET scanners, with a separate radiation source (e.g. [^{68}Ge]) for the transmission measurement, allow for acquiring the attenuation data in histogram-mode only. For an accurate motion correction, however, the patient motion occurring during the several minutes lasting transmission phase also needs to be corrected. This requires the transmission to be processed in list-mode, too.**

In our study we analysed the hardware and software possibilities and requirements – here of an ACS2-based PET scanner (ECAT Exact HR^{+}, Siemens/CTI, Knoxville, Tennessee) – to enable the attenuation measurement to be processed in list-mode. Together with some analysis on motion corrected phantom studies, this should demonstrate the advantages of a fully motion corrected study compared to an emission-corrected study only.

I. Introduction

For an accurate compensation of patient motion the acquisition data of the several minutes lasting transmission phase have to be corrected in addition to the emission data. Existing motion compensation methods, however, usually consider the compensation of patient motion during the emission phase only [1], [2], [3]. This is, apart from other reasons, the case because commonly used PET scanners, like the widely used ECAT Exact HR^{+} (Siemens/CTI, Knoxville, Tennessee), allow to acquire list-mode data during the emission phase only.

In previous studies [4], [5] we have already demonstrated methods for the optimised acquisition of list-mode data with this PET scanner type. We have been able to speed up the transfer of list-mode data with this scanner type considerably by a factor of 140×. One essential part of this work has been the analysis of the hardware and software of the underlying *acquisition control system* (ACS2) and the ECAT workstation that is connected to the PET gantry.

*J. Langner is with the PET centre, Forschungszentrum Dresden-Rossendorf, Dresden, Germany, (e-mail: j.langner@fzd.de)

H. Mölle and S. Dittrich and E. Will are with the PET centre, Forschungszentrum Dresden-Rossendorf, Dresden, Germany, (e-mail: h.moelle@fzd.de; soeren.dittrich@fzd.de; e.will@fzd.de)

J. van den Hoff is with the Department of Nuclear Medicine, Technical University of Dresden, Dresden, Germany, and also with the PET centre, Forschungszentrum Dresden-Rossendorf, Dresden, Germany, (e-mail: j.van_den_hoff@fzd.de)

For the present work we have carried out a more detailed analysis of the software constraints and the principles of the acquisition process of an HR^{+} in general.

II. Methods

During an emission scan, all registered coincidence events in a list-mode data stream are explicitly marked as so-called *event words* – a compact representation of the registered line-of-responses (LOR) within the field-of-view (FOV) of the scanner. During a transmission scan, however, the transmission sources of a HR^{+} are constantly rotating around the Z-axis of the scanner gantry and thus scan only a limited portion of the FOV at a time (cf. figure 1). Compared to an emission, only a limited amount of possible LORs are therefore available at each individual position of the [^{68}Ge] sources.

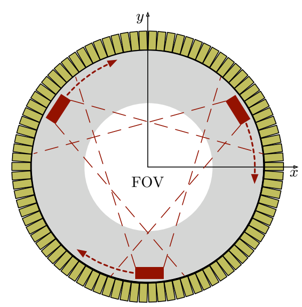

Fig. 1. Schematic view of the three rotating radioactive transmission sources [^{68}Ge] located in an ECAT Exact HR^{+} PET scanner.

To allow for a transmission scan in list-mode, we have developed a new acquisition protocol to extract the radioactive sources during a standard list-mode scan, thus simulating a transmission measurement. In several consecutive steps, we analysed the list-mode data of the simulated transmission and compared it to the known list-mode format. By application of the results of this detailed analysis, an existing list-mode sorter software (*lmSorter*) has been modified to take into account the identified differences in the data encoding.

In several test acquisitions with phantom data (5 min lasting 2D-transmissions), the validity of the list-mode transmission was verified and quantified. For this purpose we used a respiratory phantom [6] and placed a steel ball at the top of the phantom (cf. figure 2). This steel ball has been modified to have a motion tracking sensitive surface which can be tracked by an optical tracking system. In a first test measurement without any motion we performed two transmission scans, one in the standard histogram-mode and another one with the

978-1-4244-2715-4/08/$25.00 ©2008 IEEE

new list-mode method. After sorting of the list-mode data and image reconstruction the data of the two data sets have been compared to each other. Via a quantitative comparison on the base of an image correlation potential differences between the two transmission methods ought to be identified. In a second test measurement the respiratory phantom has been activated (9 motion phases per minute) while the optical tracking system recorded the motion. After application of an amplitude-based filtering a gated transmission data set has been generated and used to illustrate the capabilities of our new method.

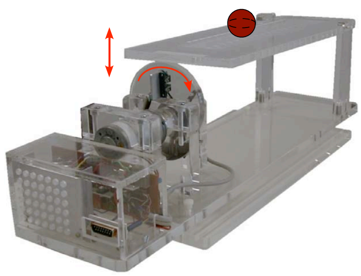

Fig. 2. Respiratory motion phantom [6] with motion tracked steel ball attached (red sphere).

III. Results

After having analysed the structure of the list-mode files obtained from the first test measurement, the data stream showed differences in the list-mode data format. Whereas *event words* in an emission scan are usually separated into delayed and non-delayed event-words only, during a transmission scan the real coincidences of the FOV-limiting transmission window are, in contrast, marked as scattered events. We have verified this by sampling the list-mode data in parallel with our DAQ-based acquisition method discussed in [4]. Furthermore, a minor amount of *event words*, as well as some of the periodically inserted *time words* in the list-mode data stream, were identified to be missing or contained invalid values. These missing or invalid data words are the result of the ACS2 directly inserting the time information into the data stream without considering the limited FOV window in transmission mode. Therefore some parts of the list-mode data are becoming invalid due to the ACS2 plainly inserting the timing information without any required synchronisation.

To verify the amount of lost and invalid data words we analysed the data sets of the first test measurement. For this purpose we modified our list-mode sorter software (*lmSorter*) and incorporated the identified differences in the scattered bit usage. Via a quantitative image correlation analysis the differences in the intensities between the histogram-mode transmission and list-mode-based transmission were found to be $< 3.5\,\%$ (deviation of image intensities from the identity line in the correlation plot) (cf. figure 3).

For a second test we performed a measurement with the respiratory phantom and the optical motion tracking activated. After the acquisition the motion data was gated according to the amplitude of the respiratory phases (cf. figure 4). For a final test of the capabilities of our list-mode-based transmission the

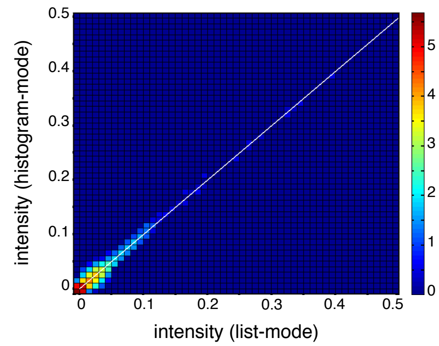

Fig. 3. Image intensity correlation histogram on the differences between a standard histogram-mode transmission and our list-mode-based transmission method. According to the deviation of the intensities from the white identity line the differences in the two methods were found to be $< 3.5\,\%$.

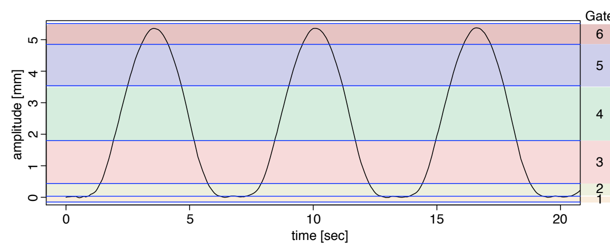

Fig. 4. The recorded motion of the steel ball with the amplitude-based gating classification.

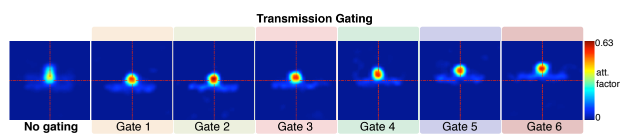

Fig. 5. Images of the gated transmission images. On the left-hand side the non-gated transmission image with the typical motion blurring is shown. On the right-hand side the transmission images with one image per gate are shown.

list-mode data of each gate have been sorted into separate sinograms and reconstructed accordingly (cf. figure 5).

One minor drawback of our method, however, is the possibility to perform 2D (with septa extracted) transmissions only. When performing a transmission scan with the septa rings retracted the list-mode data was found to be not automatically limited to the FOV of each transmission source anymore. This makes it impossible to use such list-mode-based transmission data during an event-driven motion compensation [2]. However, it still allows to apply motion compensation techniques such as gated acquisition. In addition, a more detailed analysis of such 3D list-mode-based transmission data is currently pending.

IV. Conclusions

Our study demonstrates the feasibility of enabling ACS2-based PET scanners for event-driven transmission scans. With only minimal modifications of the standard acquisition protocols and modifications in the coincidence sorter software, a motion corrected transmission sinogram can be derived from the obtained list-mode-based transmission data. Due to the generally higher time resolution of list-mode data, a transmission-aware motion compensation shows a clear advantage over solely emission-based motion correction. For developments in the field of upcoming PET/MR scanners where an MRI scan takes considerable time, our study also demonstrates the general necessity for a motion correction when deriving the PET attenuation data from the MR modality.

REFERENCES

[1] Y. Picard and C. Thompson, "Motion correction of PET images using multiple acquisition frames," *IEEE Transactions on Medical Imaging*, vol. 16, no. 2, pp. 137–144, 1997. 1

[2] P. Bühler, U. Just, E. Will, J. Kotzerke, and J. van den Hoff, "An accurate method for correction of head movement in PET," *IEEE Transactions on Medical Imaging*, vol. 23, no. 9, pp. 1176–1185, 2004. 1, 2

[3] J. Langner, "Development of a Parallel Computing Optimized Head Movement Correction Method in Positron Emission Tomography," Master's thesis, University of Applied Sciences Dresden and Research Center Dresden-Rossendorf, 2003. [Online]. Available: http://www.jens-langner.de/ftp/MScThesis.pdf 1

[4] J. Langner, P. Bühler, U. Just, C. Pötzsch, E. Will, and J. van den Hoff, "Optimized List-Mode Acquisition and Data Processing Procedures for ACS2 Based PET Systems," *Z. Med. Phys.*, vol. 16, no. 1, pp. 75–82, 2006. 1, 2

[5] J. Langner, P. Bühler, U. Just, C. Pötzsch, E. Will, and J. van den Hoff, "Optimized List-Mode Acquisition and Data Processing Procedures for ACS2 Based PET Systems," in *IEEE Medical Imaging Conference San Diego*. IEEE, November 2006. 1

[6] C. Richter, "Der Einfluss der Atembewegung auf die PET/CT-Schwächungskorrektur," Master's thesis, Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Germany, 2007. 1, 2