QUALITY CONTROL IN PET SYSTEMS EMPLOYING 2-D MODULAR DETECTORS

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ABSTRACT

Many new PET scanner designs employ 2-D detector modules to cost effectively achieve higher image and axial resolution. These systems are potentially less stable than older designs and the loss of a single photomultiplier can disable a large section of a multislice PET system. Because of these factors, it is now necessary to develop more sophisticated quality control procedures that are designed to detect problems as early as possible. We have developed and put into operation three automated quality control procedures that are designed to detect problems quickly with a minimum effort on the part of the user. These tests check : 1) stability of the detector modules in terms of efficiency, 2) resolution and its uniformity, 3) the reproducibility of the data.

INTRODUCTION

To achieve higher spatial resolution many of the new PET scanners are built with 2-D modular detectors [1,2] (e.g. CTI 831, 931, 933. CTI Inc. Knoxwill, Tennessee; scanditronix PET camera, Scanditronix Inc. Uppsala, Sweden; Posicam, Positron Corp. Houston, Texas). With the advent of the 2-D modular detector arrays on PET systems, quality control procedures become more critical to the day to day operation of the scanner. In high resolution systems with a single detector per photomultiplier (PMT), the change in gain or loss of a PMT or a number of PMT's, provided they were not clustered in a single area, usually had a negligible effect on image quality or quantitation. Only 0.2 to 0.4 % of the data would be lost per detector and this data is distributed over the whole field of view (FOV). Also the poor energy resolution of the BGO led to low energy discriminator settings, and a large gain shift was required to cause serious problems. The systems were stable and only required weekly or monthly calibration.

With 2-D modular detectors, the loss of one PMT can disable a large part of a multislice system. On the CTI Model 831 Neuro-PET system, the loss of one PMT will disable 8 of the 15 image planes. In addition smaller gain shifts will cause mispositioning of data, both within the slice and from slice to slice [3]. It was imperative to develop quality control procedures to detect problems at an early stage to schedule adjustments or replacements before malfuntion forced down time on the scanner. In developing these quality control procedures we had five general guidelines in mind. These procedures would be: 1) automated. 2) performed quickly 3) convenient for the technologist 4) testing the quality of the final product of the scanner i.e. the image, as well as lower level systems such as detector modules. 5) using the scanner with the same conditions as it is most commonly used (such as the choice of the reconstruction filter, count rates, etc.).

We have developed three quality control procedures which check the following:

1) Stability of the system in terms of the efficiencies of the detectors in a module or block.

2) Resolution and its uniformity throughout the FOV.

3) Stability of the whole system in terms of data reproducibility.

EFFICIENCIES OF THE DETECTORS IN A BLOCK.

2-D modular detector systems.

In the CTI version of a 2-D modular detector system, or detector block, a BGO crystal is cut into a 4 by 8 matrix with cuts of different depths, and is coupled to four PMT's (Fig.1), and this module is referred to as a Block Detector. The cuts allow the crystal to act as its own light guide and the ratios of the PMT signals are used to identify the incident detector. The CTI-831 PET scanner has two rings of block detectors or 8 rings of 320 individual detectors.

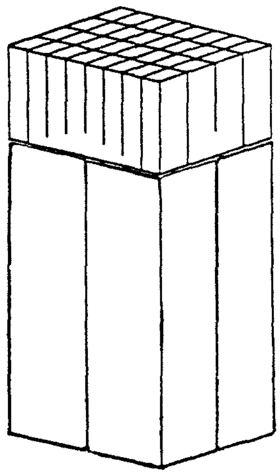

Fig. 1) Schematic drawing of the 2-D modular detector used in CTI PET scanner. This module consists of a 4 by 8 matrix cut from a single block of BGO coupled to four 1 inch square PMTs.

Test of stability of detector efficiencies

The detection efficiency of the Block Detector is inherently non-uniform. The most prominent feature of the non-uniformity is about a 10 percent lower efficiency of outer detectors compared to the inner detectors in the individual blocks. This appears as a diamond pattern in the sinogram overlaying the true source distribution. The efficiencies of individual detectors are calibrated or normalized with the PET equivalent of a flood source so that the activity after attenuation correction in a uniform phantom (e.g. a cylinder) will be constant throughout the image and from slice to slice. After this calibration the individual normalized count rates of detector pairs should all be the same for a common source of activity. Any deviation is a measure of gain shift during or some malfunction in the detection system.

The CTI-831 has 450,560 detector pairs in coincidence and to get precision on the order of one percent in each detector pair would require the accumulation of about 3 billion events, or about one hour of data collection at 1 million true events per second. This length of time would be too long for a daily quality control check and the count rate is not typical of scans which tend to be on the order of 100,000 cps. or less. We took advantage of the fact that the total count rate across an axially symmetric uniform phantom should be identical at every angle or in the case of a fan beam geometry, each fan. The coincidence of each detector with all other detectors is equivalent to a fan beam geometry.

The data for the test is collected with a centered uniform phantom or the plane source, used for normalization, rotating in the center of the FOV. The data for all coincidences of each detector element is summed across the FOV. The value of all these sums should be the same within statistical error. Since the functional unit of the scanner is the individual Block or module the data were grouped into sets corresponding to all events involving each module. For each block a parameter (T_b) similar to a chi-square is calculated.

$$T_b = \frac{1}{N-1} \sum_i \frac{((1 - P_i) \times X_i)^2}{X_i} \qquad \text{Eq. 1}$$

Where X_i is the number of counts collected by the detector i in the block b, and P_i is the ratio of X_i to the mean value of all detectors. High values of T_b indicate malfunctioning of the block b. This procedure singles out those blocks which have nonuniform detector efficiencies.

The data is collected by using a cylinder (20 cm diameter 20 cm long) filled with water and 2 miliCurie of Ge-68 which has a half-life of 288 days. The plots of T_b vs. block number for three different scanning times are shown in Fig. 2. It can be seen that for scanning times more than 9 minutes there are enough counts to make the test reliable. In this data the block number 41 shows the most nonuniformity. This quality control procedure is conducted every day at our institution and gradual deterioration of a particular detector can be monitored daily, and therefore one can anticipate problems before they are serious enough to disable the scanner.

RESOLUTION AND RESOLUTION UNIFORMITY

Resolution, resolution uniformity, and placement of the data of the PET scanner are parameters which may deteriorate over time because of the drift in the gains of the detectors or their energy windows. It is important to test these parameters periodically and correct the scanner in case of malfunction. To do this a multiple line source phantom and repositioning fixture was built. The phantom consists of a solid lucite cylinder (21 cm. in diameter, 17 cm. long.) with a set of axial holes at 2 cm. intervals. Each hole is 3 mm. in diameter and is filled with a positron emitting isotope. In total the phantom has 76 of these holes. Total radioactivity in the phantom is 2 miliCuries. An image (256 by 256 pixels) of this phantom reconstructed with a ramp filter is shown in Fig. 3. A computer program was developed to find the center of each source in each plane, calculate the distance of each center from neighboring centers, and then find the

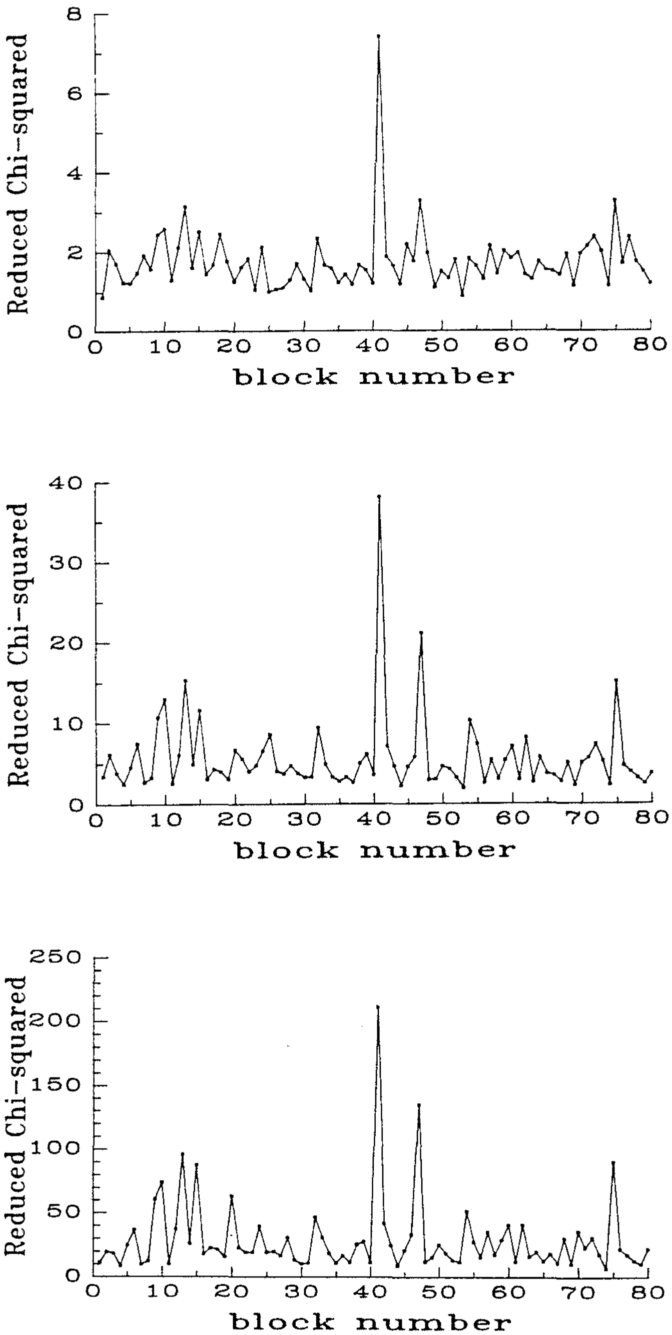

Fig. 2) Plot of T_b Vs. Block number. T_b is defined in Eq. 1 and is similar to reduced chi-square. This plot shows the nonuniformity of the efficiencies of detectors in every block. Data was collected for a) 1 minute , b) 9 minutes, c) 64 minutes. All three of the curves show that block number 41 and to some degree block number 47 have more nonuniformity . The similarity between the curves in plots b and c indicate that for scanning times more than 9 minutes there are enough counts to make the test reliable.

standard deviation of these distances with respect to the average distance. This would indicate mispositioning and nonuniformity in each plane.

A second program compares the position of each center with the corresponding ones in other planes to check for mispositioning from slice to slice. To test the stability of the resolution, the FWHM and FWTM are calculated for each line source in each plane and compared to the corresponding values that were obtained when the system was properly tuned.

To further check the resolution stability, the measured FWHM and FWTM in different positions in the FOV are compared with their average values and a map of the standard deviations are generated for each plane.

This quality control procedure will be performed every one or two months depending upon future experience.

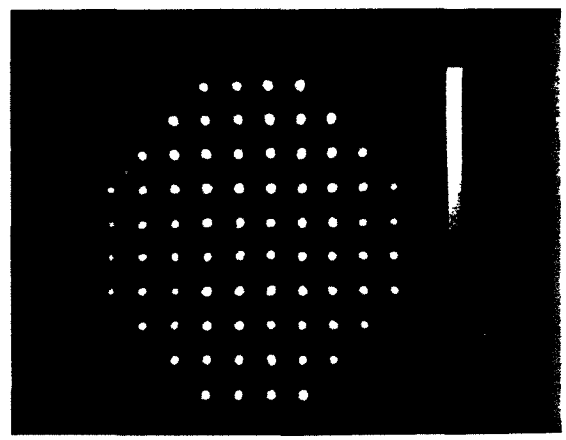

Fig. . 3) A two milion counts image of the resolution phantom. This phantom is a solid lucite cylinder with a set of axial holes at 2 cm. intervals. The holes are 3 mm in diameter and are filled with a positron emitting isotope (C-11 in this case). A computer program locates the center of each source and calculates the distance to neighboring centers, therefore detecting nonuniformity and mispositioning.

STABILITY OF PRECISION OF THE SCANNER

To routinely measure the precision or reproducibility of the PET scanner we collect 20 scans of a cylinder filled with Ge-68 solution (the same as procedure number 1). Each scan takes 5 minutes which generates about 1.2 million counts in cross-plane slices. The average counts/pixel for five small regions of interests (ROI), each 100 pixels, is measured. These regions of interests are located in different parts of the image, one in the center and one at each quadrant.

The same regions are considered for all 20 scans. If the reproducibility is good, the standard deviation of ROI values for the 20 scans would be small compared to their averages. The calculation is repeated for each of the 15 slices. The ratio of the standard deviation to the average for each ROI, or the percent error, is compared each time to those found when the scanner was well tuned. The typical percent errors found in this fashion for 1.2 million counts per plane is 5%, and for 600,000 per plane is 8%.

SUMMARY AND OUTLOOK

With the Positron Emission Tomography becoming more widely used for both clinical diagnosis and research, and most of the new PET scanners employing 2-D modular detectors, it become increasingly important to develop routine quality control procedures. We have developed three quality control procedures which are automatic and do not take a long time. The first procedures check the stability of the detector modules in terms of uniformity of detector efficiencies by conducting a chi-square type test on the count rates of each detector in a block. In order to check resolution and its uniformity and also the placement of the data in the PET scans, a cylindrical lucite phantom was fabricated which has a set of axial holes placed at 2 cm. intervals. A computer program is developed to analyze the images produced by this phantom and determine deviations from the normal resolution and correct placement of the data. A third procedure examines the reproducibility of the system by scanning a cylinder filled with a solution of Ge-68 several times, and comparing the count rates in a small region of interest.

We plan to learn from our experience by using these quality control procedures regularly to find the correct frequency for each tests.

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