Original Research Article

Assessment of Quality Control Uniformity & linearity of SPECT Gamma Camera using Image Processing

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Abstract: Assessment of uniformity to SPECT gamma camera using developing Algorithm via image processing procedure, in this study, separate algorithm was developed to quantify the linearity and uniformity (integral, and differential) using Modulation Transfer Function (MTF). The data of were collected from Royal Care International Hospital RCIH and Radiation and Isotope Center of Khartoum RICK in Nuclear Medicine Departments in the period from 2015 to 2017; images of QC test were taken from SPECT gamma camera as DICOM format to be suitable for Interactive Data Language (IDL) software to quantify the linearity and uniformity. The result showed that the uniformity for useful central field of view for integral uniformity 2.97%. While row differential uniformity 1.96% and column differential uniformity 1.55% similar to build in routine, and the linearity showed that for vertical location the variation from the original location of the line it was 0.02 mm which indicates that almost the point's falls in the line with a correlation coefficient of 0.998. In conclusion, the developed algorithm can be used to assess all gamma camera QC image for uniformity and linearity regardless of the machine brand objectively.
Keywords: Uniformity, Linearity, SPECT, Image Processing.

INTRODUCTION

There is no universal agreement on a protocol for quality control program [1-3]. Opinions vary widely on what are the minimum necessary tests and their frequency.

Possibly the most widely recognized set of camera performance tests is that proposed by the National Electrical Manufacturers Association (NEMA) from the Nuclear Imaging Section of the Diagnostic Imaging and Therapy Systems Division [4,5].

Uniformity measurement is the most important QC test, it is performed daily and is designed to verify camera spatial uniformity and measure deviations from perfectly uniform count distributions. Both intrinsic (acquired without a collimator and using a point source) and system (with collimator measured with a flood source) uniformities are analyzed using the same method.

According to NEMA, the acquired data should be collapsed into a matrix with pixel size equal to 6.4T1.9 mm and filtered with a smoothing filter.

The values of integral or differential uniformities, defined as

$$\text{Uniformity}(\%) = \left(\frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}\right) \times 100\%$$

Are calculated over the whole area of the camera or over five consecutive pixels, respectively. Max and Min are the maximum and minimum pixel counts, respectively. Both calculations are done for the full useful field of view (UFOV) of the camera and the central field of view (CFOV) corresponding to the middle 75% of the UFOV.

Spatial uniformity

There are a number of quantitative measures of spatial uniformity used in the quality control of medical gamma cameras. Standard measurements include the coefficient of deviation (the ratio of standard deviation in counts to mean counts quoted as a percentage), integral uniformity and differential uniformity. IPEM Report 86 [6] suggests that at least one integral and one differential value should be quoted with preference given to the coefficient of variation and the spread of differential uniformity as the most effective methods [7], where C is the number of counts per pixel [8] [9].

$$IU = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} \times 100\%$$

Integral uniformity is defined as the largest variation (maximum - minimum) in counts over the useful field of view, while differential uniformity is a measurement of the worst-case rate of change of uniformity over a limited distance (~5 pixels). Modern gamma camera systems typically have integral and differential uniformities of between 4-7%.

Non-uniformities of this magnitude can generate ring artifacts in tomographic data [10], hence all tomographic systems apply an additional correction to the raw image data, called "uniformity", "flood" or "sensitivity" correction, before data reconstruction.

Following uniformity correction, a tomographic system in good working order will have values of differential uniformity in the range 1.0-2.5%, with values of integral uniformity a little higher at 1.5-3.5%.

These measures give an idea of global uniformity but do not look at local variations. Differential uniformity (DU) can be calculated by using Equation [7] for only a localized number of pixels. IPEM standards suggest calculating differential uniformity 10 times for each pixel, using the five nearest pixels in a row and a column, across an entire image [6].

Uniformity should be reported with both an integral (across the entire detector) and differential (for localized groups of pixels) parameter.

Linearity

Spatial linearity is one of the parameters that influence flood field uniformity. In the ideal system, a straight-line source of gamma rays should yield a straight line in the image. Any deviation from a straight line represents distortion. Because of the finite number of PM tubes in scintillation cameras there is a wave like distortion in the image of a line source. Quantitative linearity correction is accomplished by many manufacturers by storing in a microprocessor a correction algorithm that shifts the positions of scintillation events the appropriate direction and distance to yield a straight line.

The NEMA protocol for measuring linearity involves the acquisition along the X and Y directions of an image from a multi-slit phantom, the same one used for the spatial resolution measurement, followed by an analysis of the line spread peak positions. Deviations of the peak position from the true location of the center of the slits is a measure of the deviation from linearity.

Typically, most departments do not measure linearity separate from either spatial resolution or flood field uniformity. A subjective evaluation of linearity is untamed when a bar phantom or an orthogonal hole phantom is imaged.

MATERIAL AND METHODS

Nucline Spirit DH-V machine was used in this study, average energy of Nucline Spirit 230V/50HZ and weight 2,100 (4,620) kg Thickness, 9.5 (3/8) mm (in) (detector characteristics) with power needed 230 VAC, 15 A; 110 VAC, 30 A. The machine is hole body scan, DIMENSIONS (HXWXD), CM (IN) (detection process, HR) 165 x 145 x 120 (65 x 57 x 47); The Collimators is LEGP, LEHR, LEUHR, MEGP, HEGP data input at camera station Intel Pentium 4, 3.06 GHz.

The machine is made in Hungary, the advantage of this device is extra-large FOV rectangular full digital high resolution detector, highly integrated, one-board detector electronic, scanning dual-line infrared auto body contour for all collimators easily movable patient table made of low attenuation (< 5%) 2.5 mm thin aluminum intelligent gantry electronics with 180 and 90 or 101 degree head positions scanning dual-line infrared auto body contour for all collimators.

Uniformity

The data collected using images taken for quality control phantom, for uniformity flood phantom was used, linear Parallel equal line phantom and for resolution quadratic bar phantom:

Fig-1: An image shows a flood phantom covered the face of gamma camera where the phantom filled with ^{99m}Tc.

The phantom floods it's the detector surface with uniform radiation fluxes and the counts collected by the gamma camera counting system must be uniform throughout the entire surface of the detector. This uniformity was checked using integral and differential uniformity. In the integral uniformity, the developed algorithm searches the image for the maximum and minim counts in the upper field of view (UFOV) and the central field of view (CFOV) the calculate uniformity for each segment using the following equation:

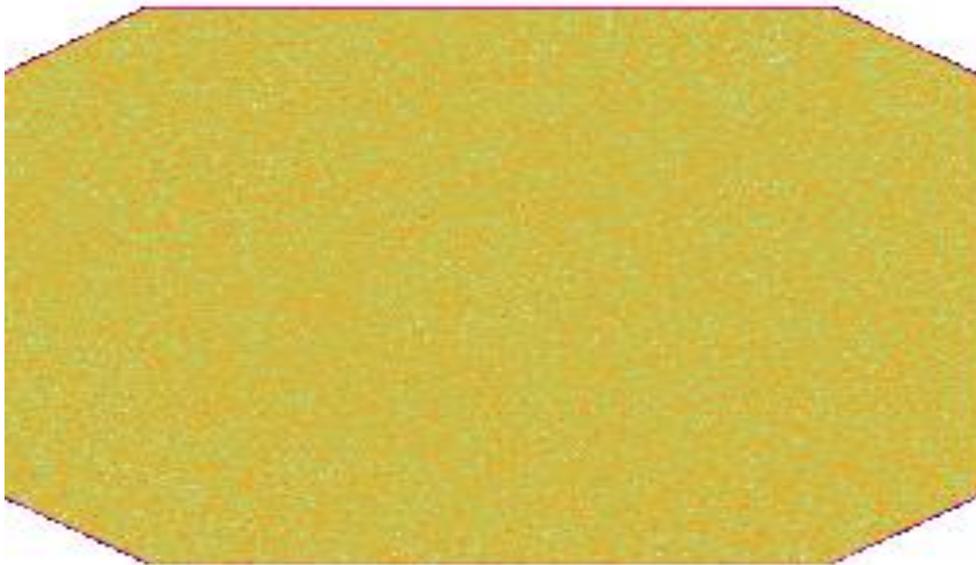*integral uniformity = ((max-count – min-counts)/ (max-count+ min-counts)) ×100*

For differential uniformity, same calculation had been performed; but instead of looking for global maximum and minimum this process carried for each 5 pixels in the raw up to the end of the row then the program moves to the next row and repeat the same process till the end of the rows. Then again same procedure followed in the columns for each 5 pixels in each column up to the end of the column. For uniformity, same equation applied for the maximum counts and minimum in the rows as well as for columns.

Linearity

System linearity depends on the camera ability to properly identify the geometric coordinates of the interaction point for a given event. The geometric distortions can be determined by imaging the slit aperture in the same way as it was done for the intrinsic spatial resolution determination followed NEMA specifications for the determination of the differential linearity and the absolute linearity. The differential linearity is defined as the standard deviation between the measured coordinates and those of the best fit to a straight line through these measured positions. The differential linearity must be specified as the mean value for the X and Y directions and for the UFOV and the CFOV.
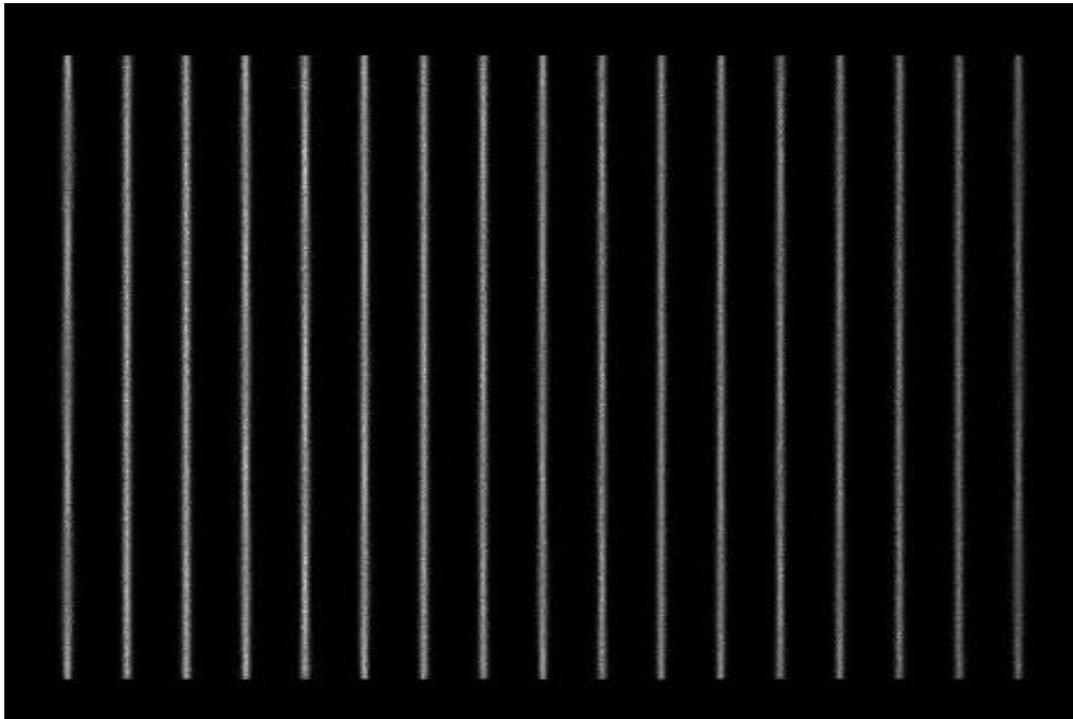
RESULTS

Fig-2: Routine intrinsic uniformity image, ^{99m}Tc, and 20% energy window set symmetrically over the 140 keV photopeak of 99mTc. For integral uniformity the Minimum counts 7132, maximum counts 7554 and for differential max counts 7132 and minimum counts 7554
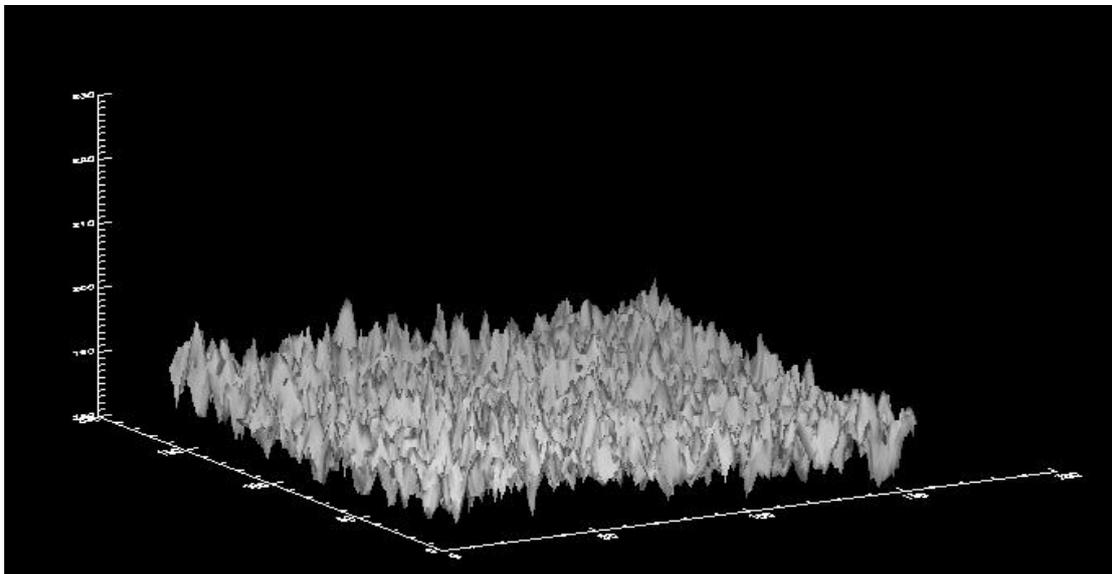
Fig-3: shade surface plot of the uniformity image shows non-uniform image subjectively.

Fig-4: Gamma camera image of Parallel-line equal-space (PLES) phantom with slit equal to one mm and a distance between them equal 30 mm arranged in X-direction.
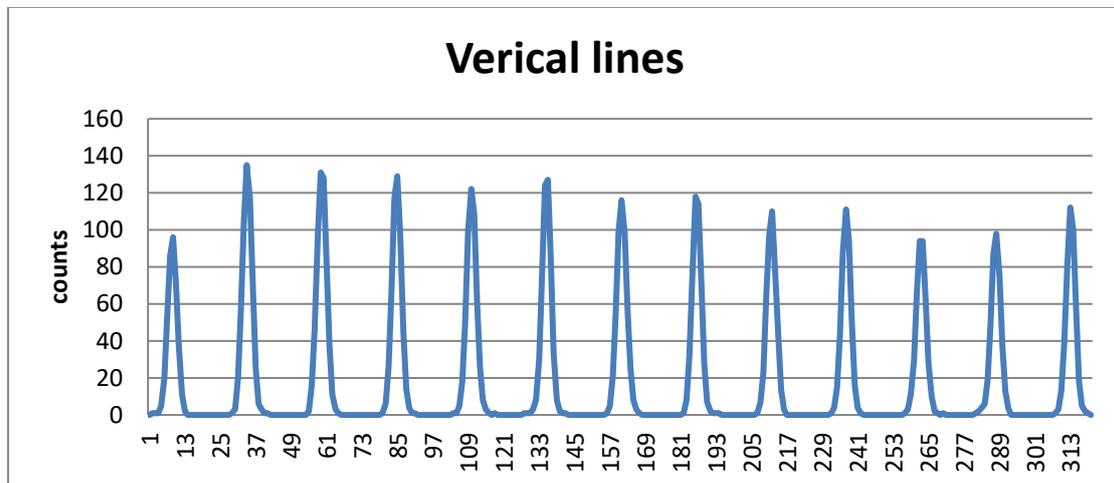
Fig-5: Line graphs of the counts across the PLES phantom in the vertical position for the center field of view.

Fig-6: Gamma camera image of Parallel-line equal-space (PLES) phantom with slit equal to one mm and a distance between them equal 30 mm arranged in Y-direction
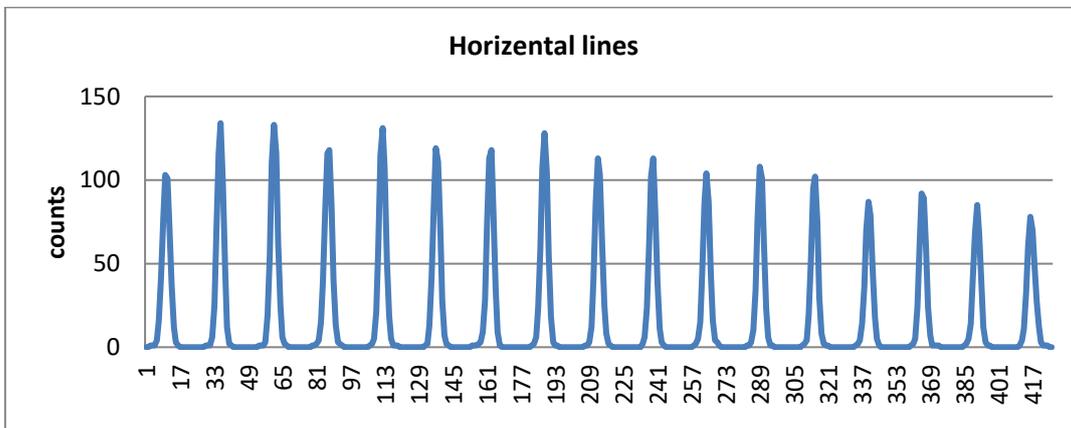

Fig-7: Line graphs of the counts across the PLES phantom in the horizontal position for the center field of view.

Fig-8: Scatter plot shows a direct linear relationship between the real locations of the slits in the phantom and the central peaks of the counts in the vertical image that corresponds to the real location by fitting a curve on the line spread function graph
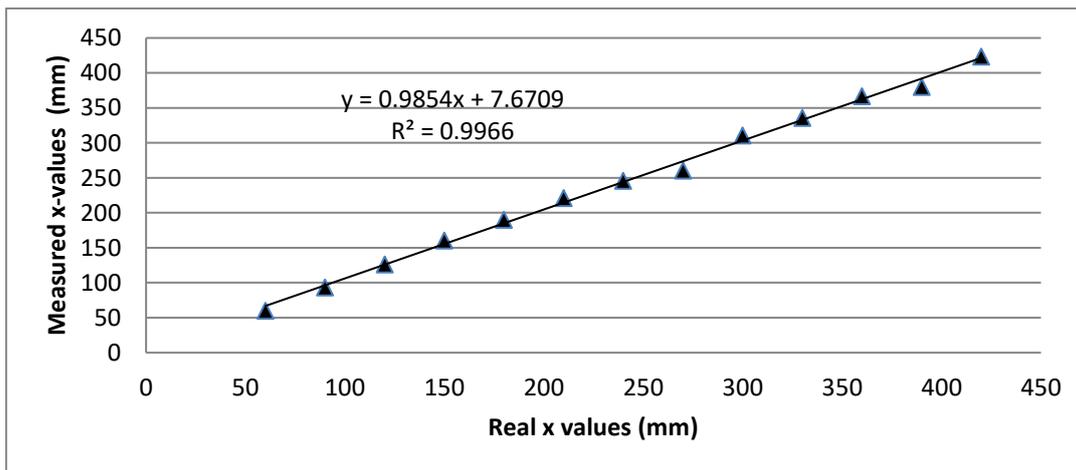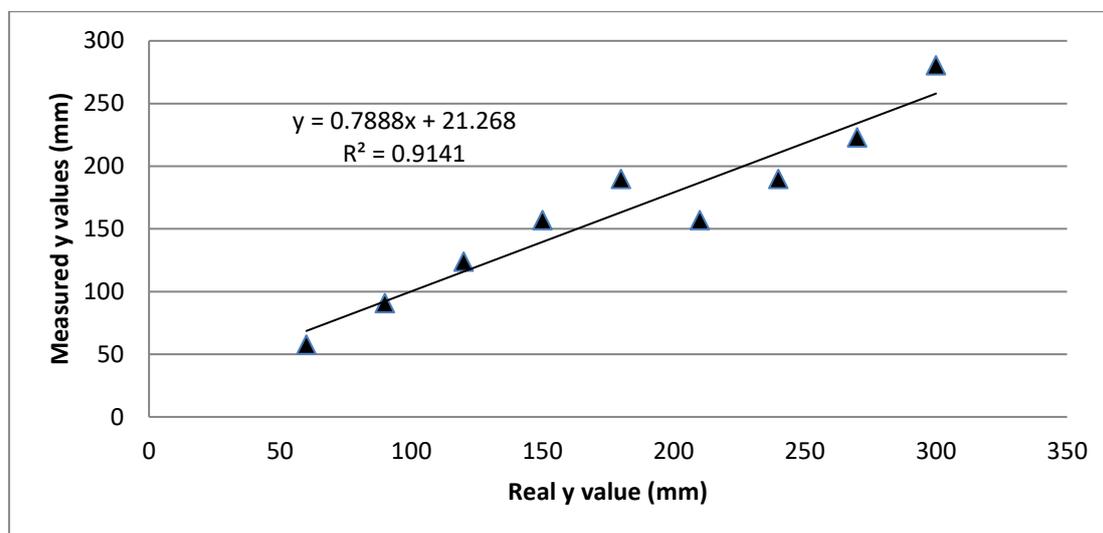
Fig-9: Scatter plot shows a direct linear relationship between the real locations of the slits in the phantom and the central peaks of the counts in the horizontal image that corresponds to the real location by fitting a curve on the line spread function graph.

DISCUSSION

The most basic measure of gamma camera performance is flood-field uniformity. This is the ability of the camera to depict a uniform distribution of activity as uniform. It is assessed by "flooding" the camera with a uniform field of radiation and then assessing the uniformity of the resulting image. The integral and differential uniformity for UFOV and CFOV was measured for image in Fig 2. using an algorithm generated by the researcher where it searches for the maximum and minimum counts for booth model of uniformity; UFOV integral uniformity was 2.87% and differential uniformity raw and column was 1.69% and 1.53% respectively. For CFOV integral uniformity was 2.97%. While row differential uniformity was 1.96% and column differential uniformity was 1.55%. The results of uniformity showed that the level of uniformity was within the tolerance range i.e. <5%; but usually correction map generated for perfection. Uniformity instead of mathematical representation which is an objective method; it can be perceived using shade-surface plot where uniformity can be easily depicted and region of problem can be identified as shown in Fig 3.

Linearity the amount of positional distortion or displacement of the measured position of photons relative to the actual position where those detected photons entered the detector i.e. for the geometrical linearity, the LSF are fitted and the standard deviation is compared to a line. In this study, the researcher adopts a new method to find the rate of change in position using a linear relationship between the actual location and the measured one; where the actual being the independent one (plotted in the x-axis). As shown in Fig 8. and 9. where the points generated from Fig 6. and 7. for the vertical and horizontal image (Fig 4. and 5.) by fitting curve one the line spread function to find the peak which equal to the location of the FWHM/2 as intensity on the x-axis. The linear scatter plot for vertical (Fig 8.) indicates that the measured value increased by 0.98 mm per 1 mm of the actual location of the line; the differences was 0.02 mm which indicates that almost the points falls in the line with a correlation coefficient of 0.998. Therefore, variation between the actual and measured line location was within a good tolerance, concerning the vertical positions. For horizontal the linear relationship between the actual and measured showed that the measured increased by 0.8mm/1mm; i.e. the difference between the two in average equal to 0.2mm, with a correlation coefficient equal to 0.956; which indicate a good tolerance but relatively low than the vertical line. This difference mainly attributed to statistical variation rather than uniformity problem which affect linearity at the end.

CONCLUSION

The developed algorithm can be used objectively and improved as required without looking for expertise from other country, as well it can be made to check the acceptance of the device performance regardless the built-in programs.

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