NEMA NU-1 2007 based and independent quality control software for gamma cameras and SPECT

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Abstract. A thorough quality assurance of gamma and SPECT cameras requires a careful handling of the measured quality control (QC) data. Most gamma camera manufacturers provide the users with camera specific QC Software. This QC software is indeed a useful tool for the following of day-to-day performance of a single camera. However, when it comes to objective performance comparison of different gamma cameras and a deeper understanding of the calculated numbers, the use of camera specific QC software without access to the source code is rather avoided. Calculations and definitions might differ, and manufacturer independent standardized results are preferred. Based upon the NEMA Standards Publication NU 1-2007, we have developed a suite of easy-to-use data handling software for processing acquired QC data providing the user with instructive images and text files with the results.

1. Introduction
Within Nuclear Medicine, image abnormalities and artifacts affecting the quality of images are well known phenomena [1]. Therefore, it is of great importance to have a thorough Quality Assurance for gamma and SPECT cameras to minimize the occurrence of these abnormalities and artifacts. EANM has made recommendations of routine quality control for nuclear medicine instrumentation [2]. After installation and before the camera is put into clinical use, it should undergo National Electrical Manufacturers Association (NEMA) Performance standard measurements to verify that the camera performs according to specification supplied by the manufacturer and to establish baseline conditions for all future measurements [3]. The NEMA Standards Publication NU 1-2007 describes how to perform, process and report QC tests for gamma and SPECT cameras [3]. Often, with support from the manufacturers, all necessary phantoms can be supplied and acquisitions can be done according to NEMA, but a thorough Quality Assurance also requires a careful handling of the measured QC data.

The lack of a manufacturer independent QC-software supporting a NEMA performance standard is a major problem performing NEMA QC tests. NEMA based software exists [4], however the number of tests is limited. Therefore, we have developed a full suite of data handling software based upon the NEMA Standard Publication NU-1 2007. Our QC software complements camera specific manufacturers’ software by providing an independent processing platform for different cameras.
2. Methods and design

The software is based on NEMA recommendations regarding processing and analysis of the data [3], and runs in MATLAB (Mathworks, Natick, Massachusetts, USA). It is capable of calculating Intrinsic Spatial Resolution and Linearity (ISR & ISL), Intrinsic Energy Resolution (IER), Intrinsic Flood Field Uniformity (IFFU), Multiple Window Spatial Resolution (MWSR), Intrinsic Count Rate Performance (ICRP), System Spatial/Scan Resolution (SSPR & SSCR), System Planar Sensitivity (SPS), System Alignment (SA), System Volume Sensitivity (SVS) and SPECT Reconstructed Spatial Resolution (SRSR).

The data handling programs are aimed at making the processing of acquired QC-data a simple task, providing the users with instructive images of the processed data as well as text files containing the results of the QC.

3. Example: Intrinsic spatial resolution and linearity

The image required for the calculation of Intrinsic Spatial Resolution and Linearity is acquired using a special lead mask (3 mm thick for Tc-99m) covering the entire Field Of View (FOV) with 1 mm wide parallel slits. The FOV is exposed by a Tc-99m point source positioned at distance of at least 5 times the maximum dimension of Useful FOV (UFOV) [3]. Figure 1 (left) shows an example of an acquired image for the determination of the ISR&L in the Y direction (trans-axial). The frames indicate the UFOV and Camera FOV (CFOV). By summing the image parallel to the direction of the slits, a number of line-spread functions is generated. Each line-spread function is characterized by a number of peaks corresponding to the number of visible slits. The main task of the Intrinsic Spatial Resolution analysis is to determine the location and the Full Width at Half Maximum (FWHM) and the Full Width at Tenth Maximum (FWTM) of these peaks.

The intrinsic spatial differential linearity is calculated as the standard deviation of the peak-locations in each slit. The intrinsic spatial absolute linearity is determined by fitting a set of equally spaced parallel lines to the peak-locations. The intrinsic spatial absolute linearity is then determined as the maximum deviation of the peak locations from the grid fit. Only if the lead mask is perfectly aligned, the grid will be orthogonal. Figure 1 (right) shows the difference between the peak locations and the best-fit orthogonal grid. Towards the left, the difference is positive, while it is negative towards the right. This indicates that the lead mask may be rotated by a small angle. By repeating the analysis, it turns out that the optimal fit is obtained by rotating the lines by 0.09 degrees, and this improves the result for the intrinsic spatial absolute linearity from 0.66 mm to 0.31 mm. Results from the processed images are shown in table 2.

![Figure 1](image.png)

Figure 1. Image acquired for the determination of the ISR&L in the Y direction (trans-axial). The frames indicate the UFOV and CFOV. The peak locations are superimposed (left). The best orthogonal grid fit superimposed on the image. The frame indicates the UFOV (middle). The difference between the peak locations and the orthogonal grid (right).
4. A novel method: Resolution and pixel size using frequency analysis

For daily qualitative inspection, flat lead or tungsten phantoms are often used in combination with a Co-57 flood source. However, a quantitative analysis of these measurements is preferred. For determining pixel size and resolution at 0 cm from the collimator, a 3 mm thick orthogonal hole lead phantom with 4 mm holes at 4 mm distance, PTW Freiburg L991151 QUASI 3, and a bar phantom with four resolution quadrants (2.5, 3, 3.5 and 4 mm slits with identical spacing) were used. The phantoms were directly placed on the collimator surface with a Co-57 flood source on top. Two to four million counts in a 256x256 matrix with 1.066 mm pixel size were acquired per image in a 122 keV (20% width) energy window. No filtering or resampling was performed.

In the discrete fourier transform, the sampling distance in frequency space, $\Delta f$ in cm$^{-1}$ and FOV in cm, are related reciprocally by

$$\Delta f = \text{FOV}^{-1} = \frac{1}{N \cdot d},$$

with $N$ the number of samples and $d$ the pixel size in cm. This gives the possibility to relate a position $i$, the number of samples times the sampling distance, in frequency space to pixel size by

$$f = i \cdot \Delta f = \frac{1}{N \cdot d}.$$

If the discrete fourier transform is applied to the images acquired with an orthogonal hole or bar phantom, this equation can be used for measuring the (average) pixel size in two directions. A non-integer value for $i$ is determined by an intensity-weighted determination of the position in frequency space.

If a gaussian point spread function is assumed, it is possible to relate the intensities in fourier space to the FWHM of the point spread function. For a gaussian, the standard deviations $\sigma$ in cartesian denoted with subscript $x$, and frequency space denoted with subscript $f$, are [5] related by

$$\sigma_x \cdot \sigma_f = \frac{1}{2 \pi},$$

while FWHM and $\sigma$ are related by

$$\text{FWHM}^2 = 8 \ln 2 \cdot \sigma^2.$$

The FWHM in cartesian space is calculated from $\sigma$ in frequency space.

An example (data from a Philips Precedence SPECT/CT) of the bar phantom and its 2D fourier transform is shown in figure 2. The resulting frequency is given as the reciprocal value of the dominant wavelength, which is 8 mm in the case of 4 mm holes/lines with identical spacing. The resolution is obtained by fitting the four intensities at the frequencies corresponding to the line distance with a gauss curve or linearly, in figure 3, by plotting the natural logarithm of the intensity against the squared frequency.

![Figure 2](image_url)
Figure 3. The natural logarithm of the intensity is plotted against the squared frequency in mm$^{-2}$ and fitted linearly. The slope is a measure for the resolution.

The obtained values were compared with NEMA measurements for two line sources of Tc-99m, placed directly on the collimator. The results are shown in table 1. The pixel size values determined with the phantoms correspond to the scanner specifications and the NEMA line source measurements. The resolution is close to the resolution determined by the line source measurements. The measured resolution can be considered as a measurement of the intrinsic resolution, if the hole diameter is small, since the phantom is placed at zero distance. The hole size, which normally is 1-1.5 mm for low energy collimators, contributes to the measured resolution with typically a few tenths of a mm. With this way, it might be more difficult to detect errors in the collimator.

| Line source | Bar phantom | Hole phantom | Specifications |
|-------------|-------------|--------------|----------------|
| Pixel size (mm) | 1.065 | 1.066 | 1.071 | 1.066 |
| Resolution (mm) | 3.93 | 3.83, 3.95 | - | 4.0 |

Gaussian, linear fit

Alternatively, the phantoms and flood source can be positioned at 10 cm distance, but this is not always easily achievable in clinical practice.

5. Results

Results processed with different software and for different SPECT are shown in table 2 and 3. Table 2 shows the output for ISR and ISL. A selection of calculated NEMA-specification is shown in table 3. Due to the manufacturers’ software, that only supports calculation of some NEMA specifications, it was not possible to process several NEMA parameters indicated by a "-" in table 3, for the SymbiaT16 and Discovery.

6. Discussion and conclusions

We have demonstrated that our software is able to calculate several NEMA specifications, and where possible, the results were compared to those obtained by the manufacturers. As shown in table 2 and 3, there is an agreement between our software and the manufacturers’ software. A novel quantitative analysis of orthogonal hole and quadrant phantoms was presented.
Table 2. ISR and ISL results based upon NEMA Standard Publication NU1-2007 processed with manufactures software and our software. Results are shown for x-direction for detector 1.

|          | SymbiaT16 manuf. results | SymbiaT16 our results | Discovery manuf. results (Xeleris) | Discovery our results |
|----------|--------------------------|-----------------------|----------------------------------|----------------------|
| ISR-x    | FWTM (mm) | FWHM (mm) | ISR-x | FWTM (mm) | FWHM (mm) | ISR-x | FWTM (mm) | FWHM (mm) | ISR-x | FWTM (mm) | FWHM (mm) |
| CFOV     | 6.9       | 3.6       | CFOV  | 6.9       | 3.7       | CFOV  | 6.5       | 3.5       | CFOV  | 6.6       | 3.5       |
| UFOV     | 7.1       | 3.7       | UFOV  | 7.1       | 3.7       | UFOV  | 6.6       | 3.5       | UFOV  | 6.6       | 3.5       |
| ISL-x    | Diff. lin. | Abs. lin. | ISL-x | Diff. lin. | Abs. lin. | ISL-x | Diff. lin. | Abs. lin. | ISL-x | Diff. lin. | Abs. lin. |
| CFOV     | 0.1       | 0.2       | CFOV  | 0.1       | 0.2       | CFOV  | 0.0       | 0.3       | CFOV  | 0.2       | 0.3       |
| UFOV     | 0.1       | 0.4       | UFOV  | 0.1       | 0.3       | UFOV  | 0.1       | 0.3       | UFOV  | 0.2       | 0.3       |

Table 3. A small selection of results based upon NEMA Standard Publication NU1-2007 calculated by different software.

|          | SymbiaT16 manuf. results | SymbiaT16 our results | Discovery manuf. results (Xeleris) | Discovery our results |
|----------|--------------------------|-----------------------|----------------------------------|----------------------|
| SPS      | LEHR coll. | LEHR coll. | LEHR coll. | LEHR coll. |
| (Cps/MBq) | - | 92 | - | 74 |
| IER      | FWHM (%) | 8.6 | 8.9 | - | - |
| SSPR     | LEHR coll. | LEHR coll. | LEHR coll. | LEHR coll. |
| FWHM (mm) | - | 7.5 | 7.6 | 7.6 |
| IFFU     | UFOVI (%) | 2.1 | 2.5 | 2.4 | 2.2 |
| SA       | Cor. 1 (mm) | - | 7.3 | - | 1.7 |
|          | Cor. 12 (mm) | - | 1.02 | - | 0.6 |
|          | Axial 1 (mm) | - | - | - | 0.5 |
|          | Axial 12 (mm) | - | 0.77 | - | 0.5 |

The selection of the platform used to code the software was MATLAB, which, in principal, is independent of the operating system. Future development could be the compilation of our software, making it independent of the MATLAB environment and an automatic report-generation using e.g. LaTeX. It is our vision that the software will be open access.

References
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