Investigation of the NPS as a Tool for Routine Quality Control of Digital X-Ray Systems

M. Ghorbanzade [1], **I. Elbakri** [1]

1University of Manitoba, Winnipeg, MB, CA.

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INTRODUCTION

Quality control (QC) guidance documents often recommend various tests for loading factors accuracy, artifact and spatial resolution of x ray imaging systems which are time consuming and require specialized tools [1]. It is desired to have an effective and efficient QC test which lends itself easily to automated analysis. The noise power spectrum (NPS) is the most common metric to characterize the noise content of the imaging system [2]. Noise in digital x ray imaging consists of three components: fixed pattern, quantum and electronic [3]. Each of these components corresponds to one or more stages of the imaging chain. Therefore, calculating the NPS can be a useful method to evaluate the system performance.

AIM

This study investigates the sensitivity of the NPS to three types of deviation in digital x ray system performance parameters: tube potential value, resolution and artifact, for QC applications. The effect of mentioned deviations on the NPS components (fixed pattern, quantum and electronic) is also investigated by decomposing the NPS to see whether the change in these components can point to the source of deviation.

METHOD

Uniform images were acquired under different conditions representing deviations from ideal performance using a digital x ray system (Definium, GE Healthcare). The linearity of detector response function was evaluated prior to NPS calculations. The normalized NPS (NNPS) was calculated using the methodology of the international electrotechnical commission [4]. The NNPS was computed for images with kV deviation (±5kV from the nominal value), resolution deviation (obtained by changing the focal spot size) and images with and without synthetically generated pixel defects. To quantify the change in the NNPS with performance deviation, the relative difference between each NNPS pairs was summed over all frequencies which will be referred to as the total relative difference (TRD). The TRD was calculated between the NNPS of multiple repeated images to estimate the range of uncertainty of the NNPS for the system used in this study.

The NPS was decomposed into its components according to equation (1) for two types of deviation: tube potential value and defective pixels artefact to see if the change in the NPS component reflects the change in the system's performance.

$$NPS(f,D) = NPS_e(f) + NPS_q(f).D + NPS_{fp}(f).D^2 \qquad (1),$$

where D is exposure and $NPS_e(f)$, $NPS_q(f)$ and $NPS_{fp}(f)$ are the electronic, quantum and fixed pattern noise power spectrum coefficients, respectively, which are fitted for each frequency bin [4], [5]. However, since the imaging system used in this study would automatically correct the output for dark current, the electronic coefficient was removed from the equation.

RESULTS

The linearity of detector's response function was confirmed (R-squared= 0.99999). The maximum TRD between the NNPS of each pair of repeated images was 0.7. Given that all measurements were performed at the same exposure level, this value represents the uncertainty of the NNPS calculations due to exposure variations and was considered as the "threshold" of the NNPS sensitivity to performance deviations in this study.

Figures 1-3 show the NNPS for three types of deviation in system performance. Results show that the NNPS decreases when the tube voltage increases. A 1 kV tube voltage deviation from 80 kV resulted in a TRD equal to 1.8 which is larger than the calculated NNPS uncertainty range. Also, the NNPS of the image acquired with large focal spot is lower than the one acquired with small focal spot and the TRD between them was 1.4 . This is because quantum noise is directly proportional to the square of the MTF [6]. When a small number of defective pixels (0.02% of total pixels) were introduced to the image, The NNPS increased. The TRD between the NNPS of the resultant and original image was 37.7.

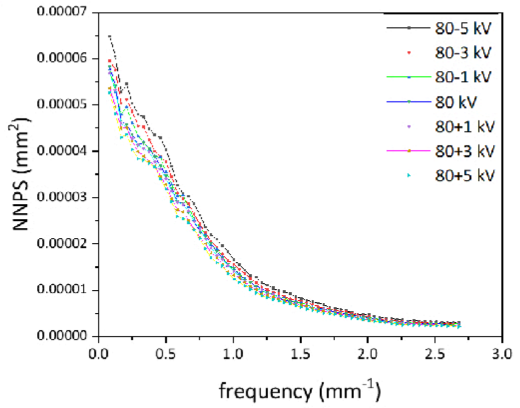

Figure 1. The NNPS change with deviation in tube potential.

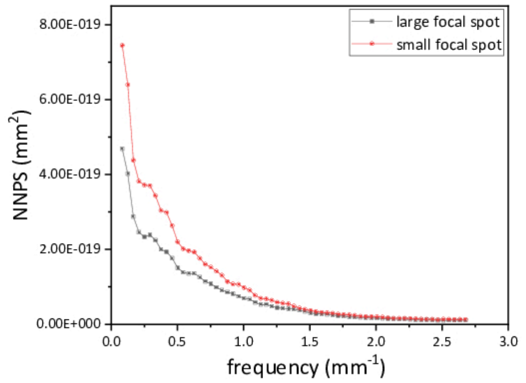

Figure 2. The NNPS for images acquired with large and small focal spot size.

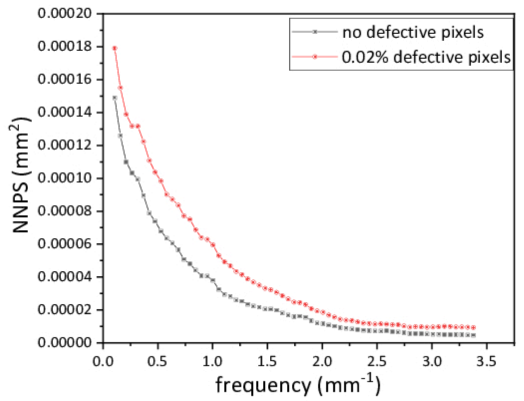

Figure 3. The NNPS of images with and without defective pixels.

Figure 4 shows the NPS components for two selected tube voltage values. The quantum and fixed pattern noise component of images with 3 kV difference in tube voltage value were compared in table 1. The difference was more pronounce for the fixed pattern noise which is in line with the fact that fixed pattern noise is proportional to the square of photon fluence. Quantum noise is also associated with the absorption of primary and secondary x ray photons. Any change in tube voltage affects the average photon energy and results in variation in penetration power of x ray photons and fluctuations in the number of absorbed secondary photons by the detector [7].

The fixed pattern and quantum NPS components of images with defective pixels are shown in figure 5. As shown in table 1, the TRD calculated for the fixed pattern component is considerably higher than the one calculated for the quantum noise. This result is consistent with the fact that defective pixels is an added structured artifact in the system and Therefore, it is expected to mostly affect the fixed pattern noise.

Table 1. The TRD of the NPS components for two different types of performance deviation.

Performance deviation type	TRD	
	Fixed pattern component	Quantum component
kV deviation	12.14	8.27
Defective pixels	40.92	3.9

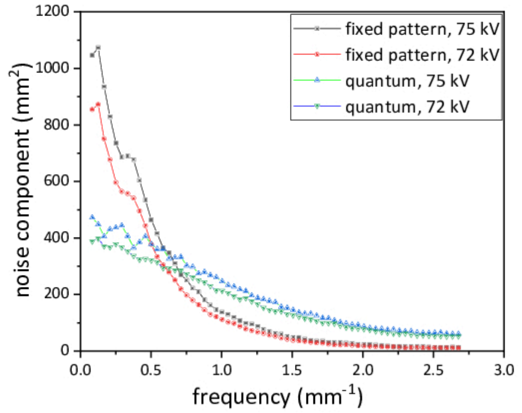

Figure 4. the NPS components for images at two different tube potential values.

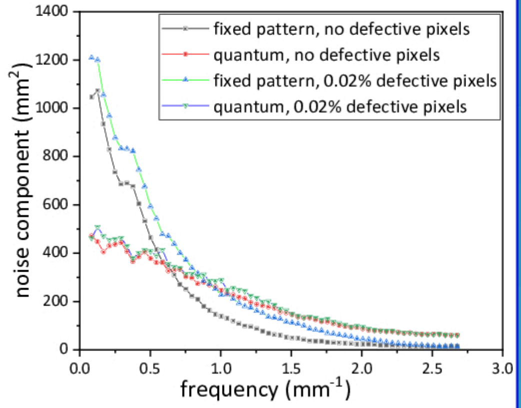

Figure 5. the NPS components for images with and without defective pixels.

CONCLUSIONS

This study proposes that the normalized NPS is sensitive to deviations in digital x ray imaging system performance parameters such as tube potential inaccuracy, resolution change and fixed pattern artifacts. Furthermore, decomposing the NPS into its components and comparing them to the NPS components of a reference image might point to the possible cause of performance deviation.

NPS calculation is a fast and simple automated procedure. Using NPS as a QC tool not only can save time, but in some cases, is also more reliable. Future work will focus on investigating the sensitivity of the NPS to other possible system performance deviations.

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CONTACT INFORMATION

Email: Ghorbanm@myumanitoba.ca

Phone: 4313368296