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Simulation-based Study of Scattered Radiation Influence on Contrast and Spatial Resolution in Projection Radiography

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Introduction

Noise is one of key quality parameters in a medical radiographic image.

Two main types of noise are quantum noise, present in any radiation-based imaging modality, and scatter noise, which is especially significant in x-ray radiography.

The present study takes a modeling approach to investigating relative contributions of these two types of noise in an image.

A flat-panel radiographic system with a flat contrast-detail phantom and a point x-ray source is represented within a Monte Carlo model.

Variable parameters in Monte Carlo simulations included the x-ray energy spectrum and the properties of the virtual phantom.

Images obtained from simulation are used for calculating signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) for various material compositions within the phantom and different x-ray spectra.

Methods and Models

An original Monte Carlo simulation code has been developed in the MATLAB software package.

The code models isotropic emission of x-rays from a point source at a SID (source-to-image receptor distance) of 107 cm.

The receptor is a flat panel with 500 x 500 dexels, and the images produced in simulations are of this same size (500 x 500 pixels).

Size of each pixel is 500 x 500 µm.

The receptor has been assumed to have 100% detection efficiency, i.e. a dexel hit by a photon of any energy has had its count incremented.

The flat panel detector has been overlaid with a 3-cm-thick flat phantom, with a 0,5 cm gap between the two. The phantom is a version of a contrast-detail phantom, with rows of metal discs (of various thicknesses and diameters) imbedded within a water-equivalent casing.

Virtual phantom used in simulations has a mash of 5 x 5 metal discs.

Diameter of metal discs within the phantom ranges from 0.8 to 4 cm, and their thickness from 1 to 2.8 cm.

The discs are made of either aluminium or copper.

Two x-ray spectra are used in various simulation runs, at 60 and 120 kVp, with 1 mm Al filtration.

Only single Compton scattering of photons within the phantom are considered. These are modelled by the Brusa algorithm for sampling scattered photon angle and energy.

[D. Brusa, G. Stutz, J.A. Riveros, J.M. Fernández-Varea, F. Salvat, *Fast sampling algorithm for the simulation of photon Compton scattering*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 379, Issue 1, 1996, pp 167-175]

10^7 photon histories are followed, counting only photons that are emitted towards the flat panel detector.

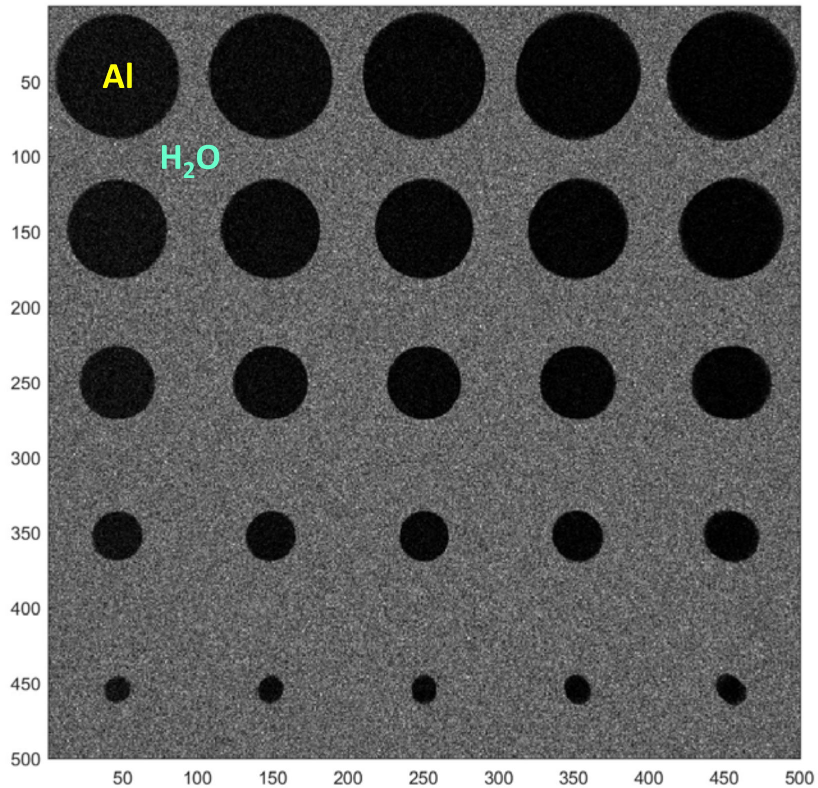
Results and Discussion

A total of eight images have been produced:

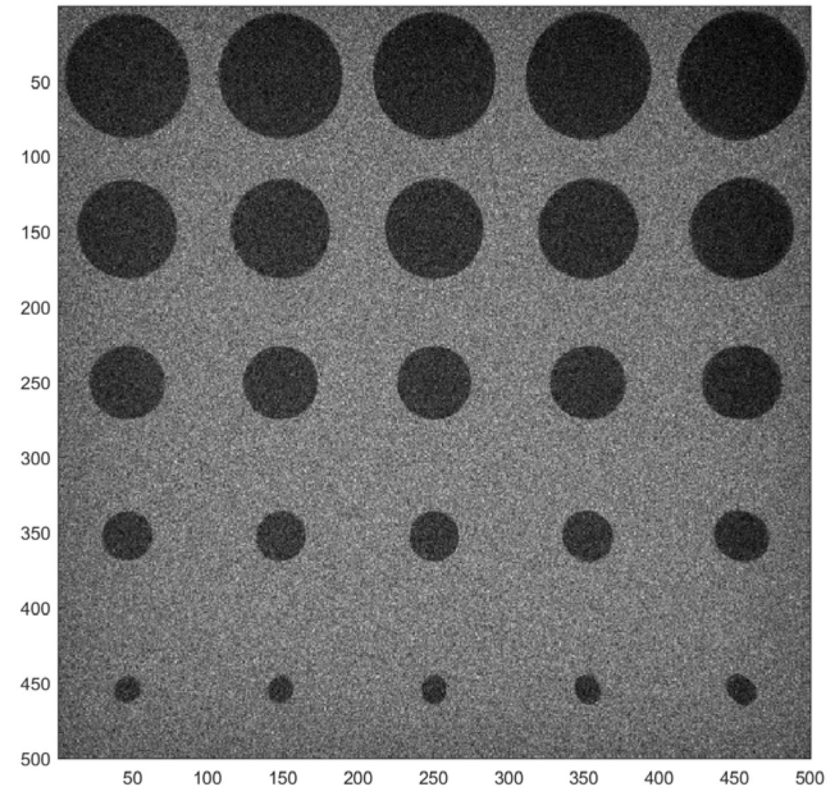
- for each of the two phantom disc materials (aluminum & copper)
- at each of the two x-ray tube voltages (60 & 120 kVp)
- with quantum noise only & with both quantum and scatter noise

Monte Carlo simulations offer an easy way of separately quantifying the contributions of quantum and scatter noise to image quality, since each photon is followed independently.

The images obtained from simulations are presented in the following slides.

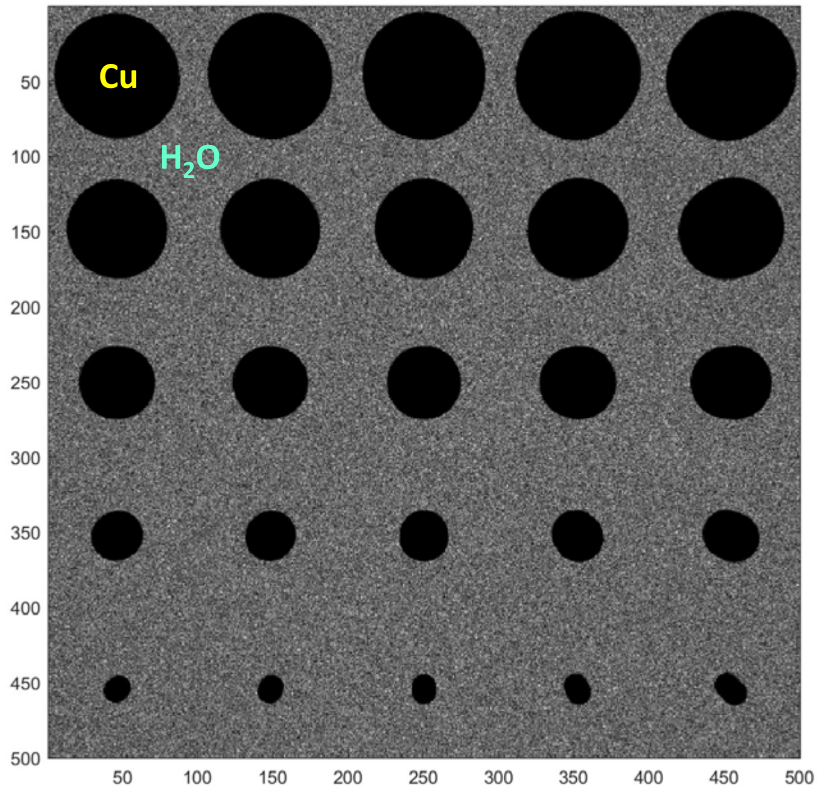


Quantum noise only

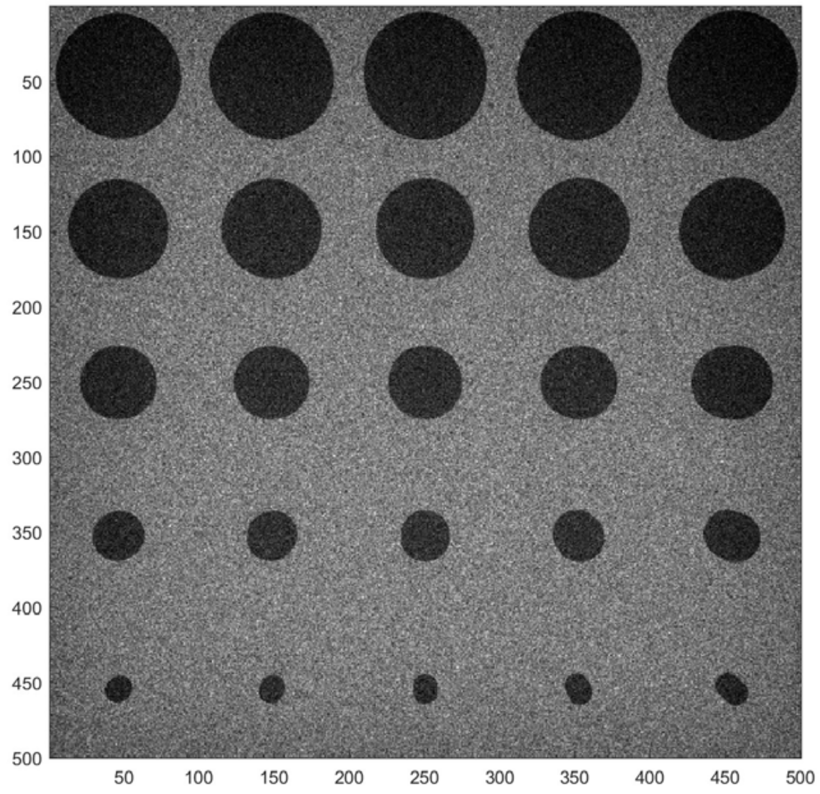


Both quantum and scatter noise

Simulation-generated images of the virtual contrast-detail phantom with aluminum discs at 60 kVp

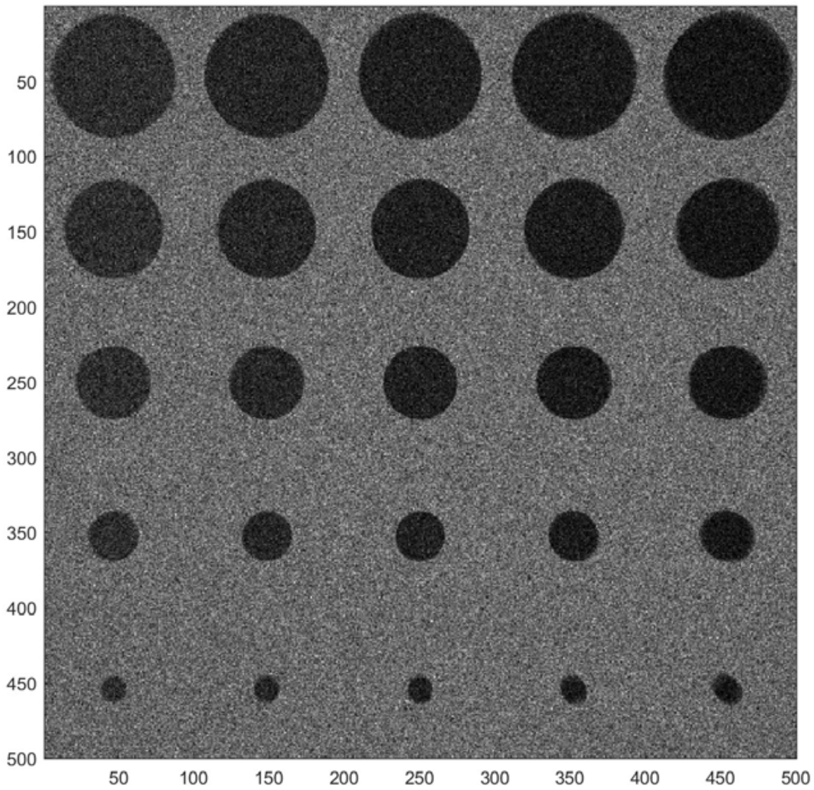


Quantum noise only

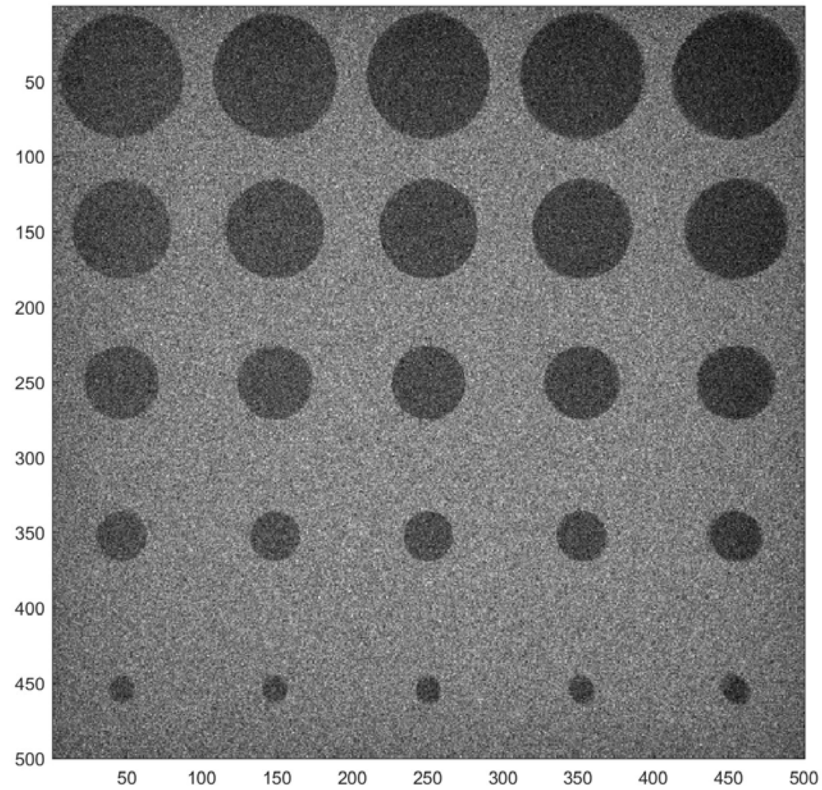


Both quantum and scatter noise

Simulation-generated images of the virtual contrast-detail phantom with copper discs at 60 kVp

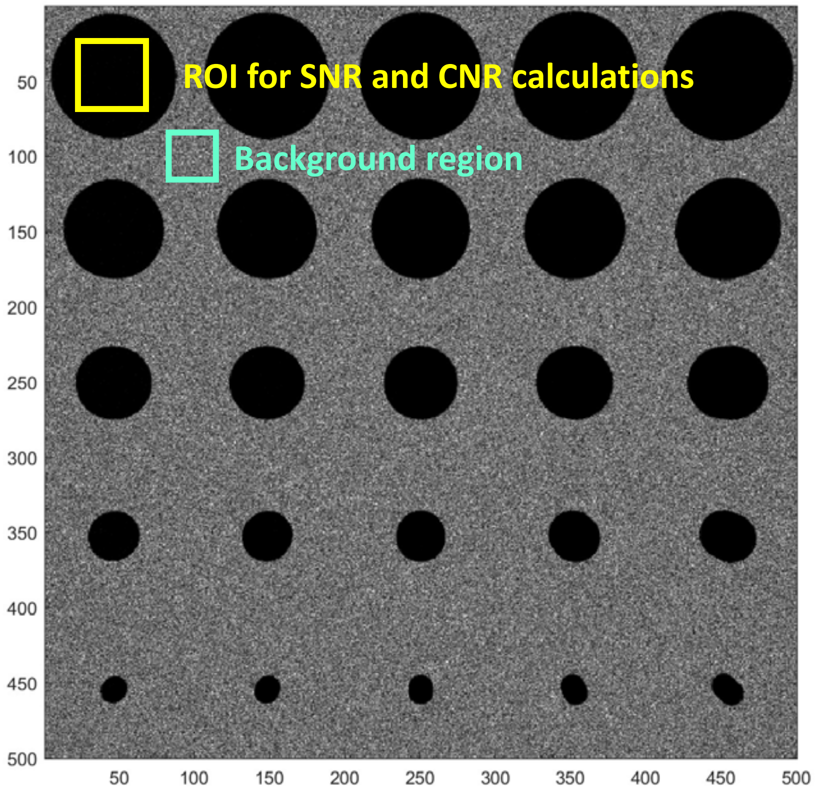


Quantum noise only

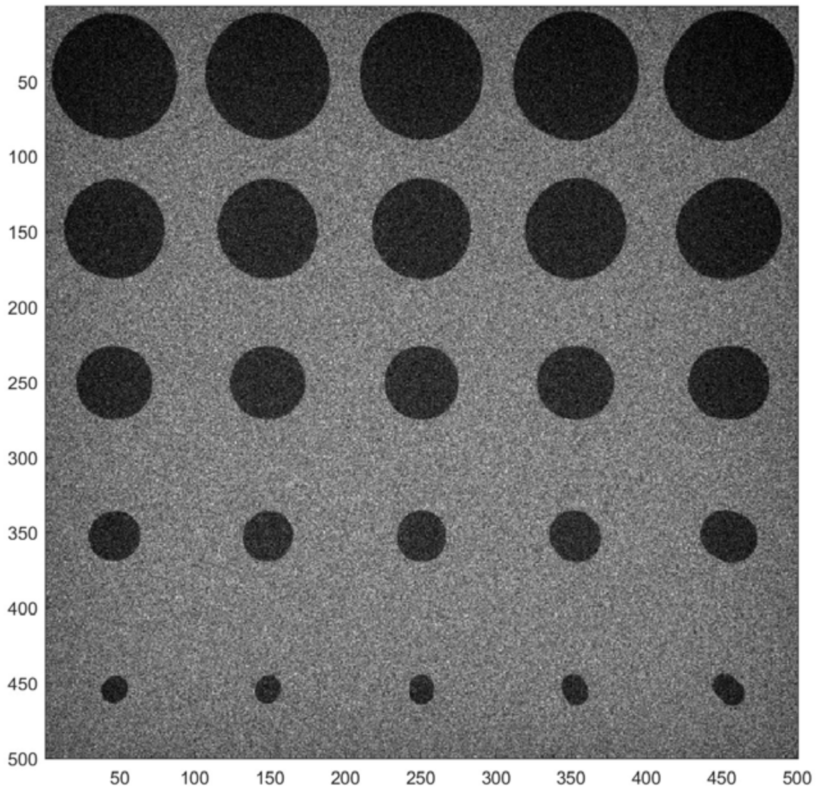


Both quantum and scatter noise

Simulation-generated images of the virtual contrast-detail phantom with aluminum discs at 120 kVp



Quantum noise only



Both quantum and scatter noise

Simulation-generated images of the virtual contrast-detail phantom with copper discs at 120 kVp

The images reveal a clear dependence of quantum and scatter noise presence on both the material used for the discs in the phantom and the tube voltage (which defines the x-ray energy spectrum).

Highest levels of scatter noise are observed with aluminium discs and at the higher tube voltage, since aluminium is a more intense scatterer than copper and also because at higher photon energies Compton scattering dominates over photoelectric absorption.

Slight distortion is observed at the corners of the images and is attributed to the divergence of the x-ray beam.

Water also acts as an efficient photon scatterer at diagnostic x-ray energies, and would contribute more to scatter noise if the phantom was thicker.

One major difference between the two investigated types of noise is that quantum noise has less effect on the disc shadow regions, especially for discs made out of copper, since copper is a more efficient absorber than aluminium. Scatter noise, on the other hand, effects the whole image – both the shadow regions and the background - almost uniformly.

Apart from being observable in the images, the dependence of noise on imaging conditions and phantom composition is also reflected by quantitative image parameters, presented in the table below.

Material	Parameter	60 kVp	120 kVp
Al	SNR (Quantum noise only)	34,3243	14,4791
	SNR (Quantum and scatter noise)	17,3890	11,7018
	CNR (Quantum noise only)	15,8104	3,4234
	CNR (Quantum and scatter noise)	3,8497	2,3179
Cu	SNR (Quantum noise only)	259,9000	255,6858
	SNR (Quantum and scatter noise)	22,3949	22,0318
	CNR (Quantum noise only)	13,6973	345,9433
	CNR (Quantum and scatter noise)	5,8120	5,7455

SNR and CNR values have been calculated from all eight images generated by the simulations, using regions marked in the last image shown above.

With specific phantom properties adopted for simulations, spatial resolution has not suffered enough from either kind of noise to make any of the metal discs nonvisible − all of the smallest discs in the lowermost row are visible in all cases.

However, for a thicker phantom, with even smaller-diameter metal disc, at least some visibility would certainly be lost, and a Monte Carlo survey, such as the one presented here, would allow the visibility threshold to be determined in any particular conditions.

Level of quantum noise depends on the (*tube current*) x (*exposure time*) product, i.e. mAs. In a Monte Carlo simulation this translates into the number of photon histories. The number of photons used herein (10^7) is enough to keep the relative uncertainty of results at a reasonably low level (< 1%), but still largely underestimates the number of photons typically present in a medical x-ray exposure, which is on the order of 10^{12}. The focus of the present study, however, is on scatter noise, while quantum noise serves more as a reference for the scatter fraction.

The obtained results indicate that imaging conditions need to be adjusted to the physical properties of the region being imaged, in order the relative contribution of scatter noise within acceptable bounds.

Conclusion

The influence of noise that appears on a flat panel detector in projection radiography due to scattered x-rays was analysed using Monte Carlo simulations.

Variable parameters in the simulations included the x-ray energy spectrum and the properties of a flat virtual phantom.

The impact of scattered radiation was considered from the perspective of image quality, for various material compositions and dimensions of metal discs within the phantom.

Contribution of scattered photons to image noise was determined and analysed separately from and in conjunction with quantum noise.

The results can provide guidelines for adapting the imaging conditions to the physical contrast, scattering properties and dimensions of structures in the region being imaged, so that a better quality image is obtained.

Thank you for the attention!

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