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# Performance analysis of a neutron and X-ray combined computed tomography system

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ABSTRACT

A novel neutron and X-ray combined computed tomography system (NXCT) has been developed at the Missouri University of Science & Technology. It is believed that it will provide a superior method for non-destructive testing and evaluation. The system is housed within the Missouri University of Science & Technology Reactor (MSTR) and is the first such imaging platform and synthesis method to be developed. The system utilizes neutrons obtained directly from the reactor core and X-rays from an X-ray generator. Characterization of the newly developed digital imaging system is imperative to the performance evaluation, as well as for describing the associated parameters. The preliminary evaluation of the NXCT system was performed in terms of image uniformity, linearity and spatial resolution. Additionally, the correlation between the applied beam intensity, the resulting image quality, and the system sensitivity was investigated. The combined neutron/X-ray digital imaging system was evaluated in terms of performance parameters and results are detailed. The Modulation Transfer Function (MTF) of the X-ray imaging module was calculated using the Edge method. The spatial frequency at 10% of the MTF was found to be 8 l p/mm, which is in agreement with the value of 8.5 l p/mm determined from the square wave response method. The highest detective quantum efficiency of the X-ray imaging module was found to be 0.53. Furthermore, the Modulation Transfer Function (MTF), Noise Power Spectrum (NPS) and Detective Quantum Efficiency (DQE) spectrum for the neutron imaging module was also evaluated in a similar way as the X-ray imaging module. In order to improve the image quality of the neutron imaging module, a pin-hole mask phantom was used to correct the geometrical non-linearity of the delay line anode readout. The non-linearity correction of the delay line anode readout has been shown through the corrected images of perforated cadmium strip and electroformed phantom.



## 1. Introduction

Neutron and X-ray imaging are widely employed imaging techniques in research, industry, and the medical field. Utilizing the advantages of both neutron and X-ray imaging techniques, which are complementary by nature, a novel combined neutron and X-ray (NXCT) imaging system has been developed at the Missouri University of Science and Technology Reactor (MSTR) [1] The capability of the new imaging system is based on image quality and the associated parameters i.e. contrast, noise and resolution [2]. Most of the developed methods such as Modulation Transfer Function, Noise Power Spectrum, and Detective Quantum Efficiency (MTF, NPS and DQE) are used to quantify the parameters and are accepted as the standard methods for imaging system performance evaluation. The MTF measurement evaluates the spatial resolution of the imaging system. It measures the ability of the imaging detector to characterize a radiation pattern whose intensity varies sinusoidally in a one dimensional plane for a corresponding distance. MTF can be calculated by the slit method, square wave method, sine wave method, sine wave response method, or the edge method [3–16]. The noise power spectrum (NPS) characterizes the image noise and the shape of the spectrum determines the frequency space where the noise power is concentrated. DQE is a measurement of the imaging system efficiency. In fact, DQE collectively evaluate the signal and noise performance of the imaging system. In short, DQE provides a collective description of the noise transfer characteristics of a detector which shows how the signal is degraded by passing through the imaging system and provides a measure that how well an imaging system can detect minute detail in an image. The performance evaluation parameters are well established and are frequently applied in the quantification of an X-ray imaging system's performance [3–16].

However, the newly developed neutron and X-ray combined imaging system requires a uniform quantification procedure that can be easily implemented for the performance evaluation of

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current combined imaging systems. Physical and geometrical characteristics of radiation sources and imaging detectors play a substantial part in developing performance evaluation criterions. In neutron radiography, American Society for Testing and Materials (ASTM) Image Quality Indicators (IQI) are common standards used to characterize the neutron image quality as well as the beam

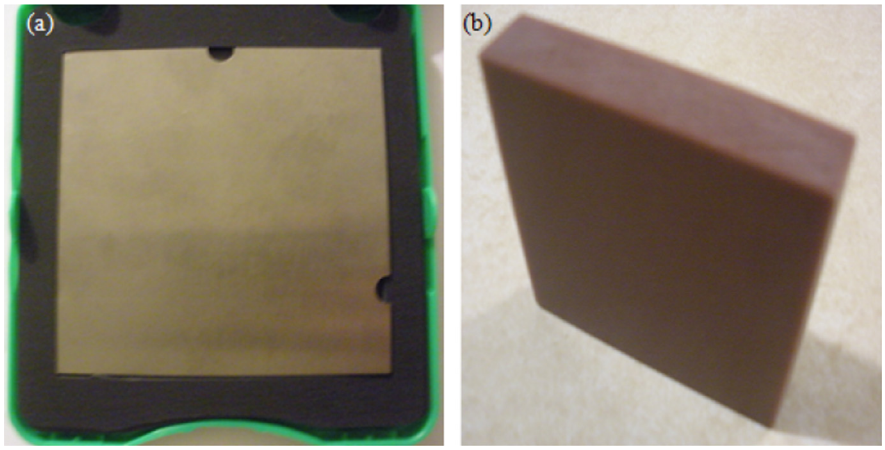


**Fig. 1.** A highly polished (a) tungsten edge phantom with two adjacent polished edges inside a protective box and (b) a solid water phantom.

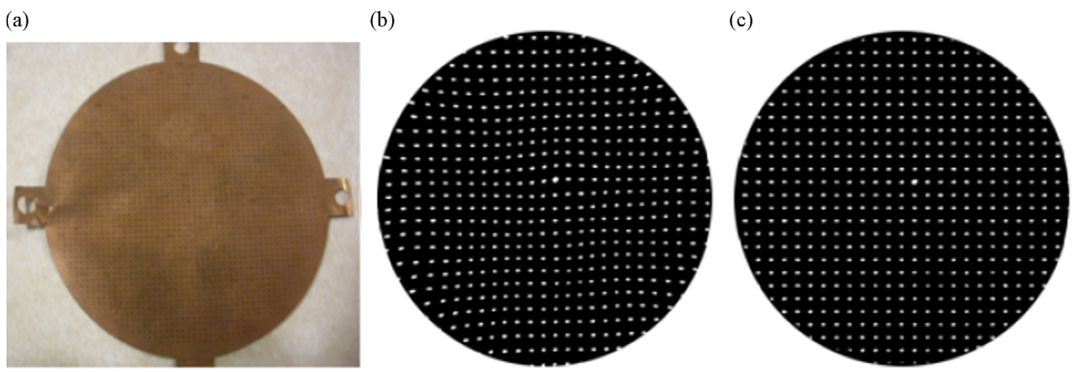


**Fig. 2.** Photograph of the pin-hole mask (a), non-linear image of the pin-hole mask from UV imaging (b), and non-linearity corrected image of the pin-hole mask (c).

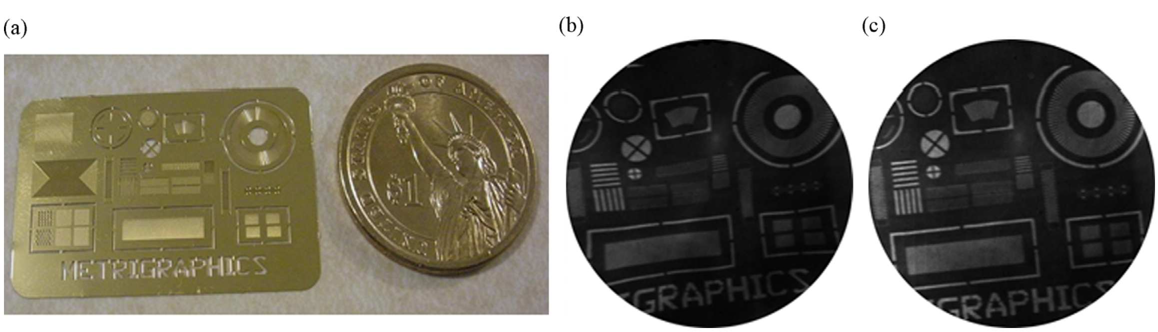


**Fig. 3.** Photograph of the electroformed phantom and $1 coin for scale (a), non-linear image of the electroformed phantom from UV imaging (b) and non-linearity corrected image of the electroformed phantom (c).

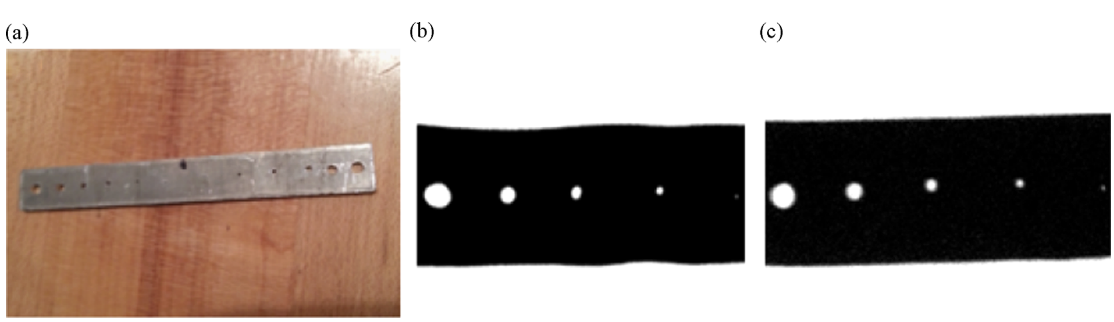


**Fig. 4.** Neutron image of perforated cadmium strip with smallest visible hole size of 0.25 mm.