Flat-Field MTF Measurements Via the Noise Response Method: Application to Fluoroscopy QC

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ABSTRACT

The modulation transfer function (MTF) is a standard metric for quantifying the spatial resolution of radiographic imaging detectors. Measurement of the MTF can be achieved through the Noise Response (NR) method, which utilizes only flat-field images for MTF determination and obviates the need for precision test objects as required by traditional techniques. The procedural simplicity of this method makes it amiable for inclusion in routine clinical quality control (QC) workflows. This study explores the feasibility of the NR method for spatial resolution consistency checks as part of an interventional radiology (IR) QC program.

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INTRODUCTION

Fluoroscopically guided interventions (FGIs) yield some of the highest radiation patient doses in clinical practice. These Class 1 radiological risk procedures [1] are often lengthy and complex, leading to potential patient harm in the form of deterministic skin reactions as well as increased staff occupational exposures. Appropriate system functionality and image quality are essential in enabling use of the lowest-dose protocols appropriate for the procedure. Implementation of quality control (QC) programs for interventional radiology (IR) can help in achieving this goal [2].

For fluoroscopy spatial resolution, traditional methods include use of line-pair phantoms or more rigorous determinations of the modulation transfer function (MTF) using precision test objects. An alternative known as the Noise Response (NR) method [3] provides accurate detector MTFs by utilizing flat-field images and a general relationship between the image noise power spectrum (NPS) and MTF. The work discussed here would allow for a straightforward MTF determination that can be performed as part of the image quality check of an IR technologist QC program.

METHODS AND MATERIALS

Single-shot, flat-field acquisitions were taken with stationary C-arms equipped with CsI indirect flat-panel detectors. Images for NPS determination were collected according to IEC standards [4], as well as with typical parameters for a recently established IR QC program at our health system (Table 1). For the IEC-compliant images, the system's Service Mode was used to disabled as much image processing (e.g., edge enhancement) as possible as well as remove any additional x-ray beam filtration. A Python script based on previously developed MATLAB scripts for NR analysis [6] was used for image analysis.

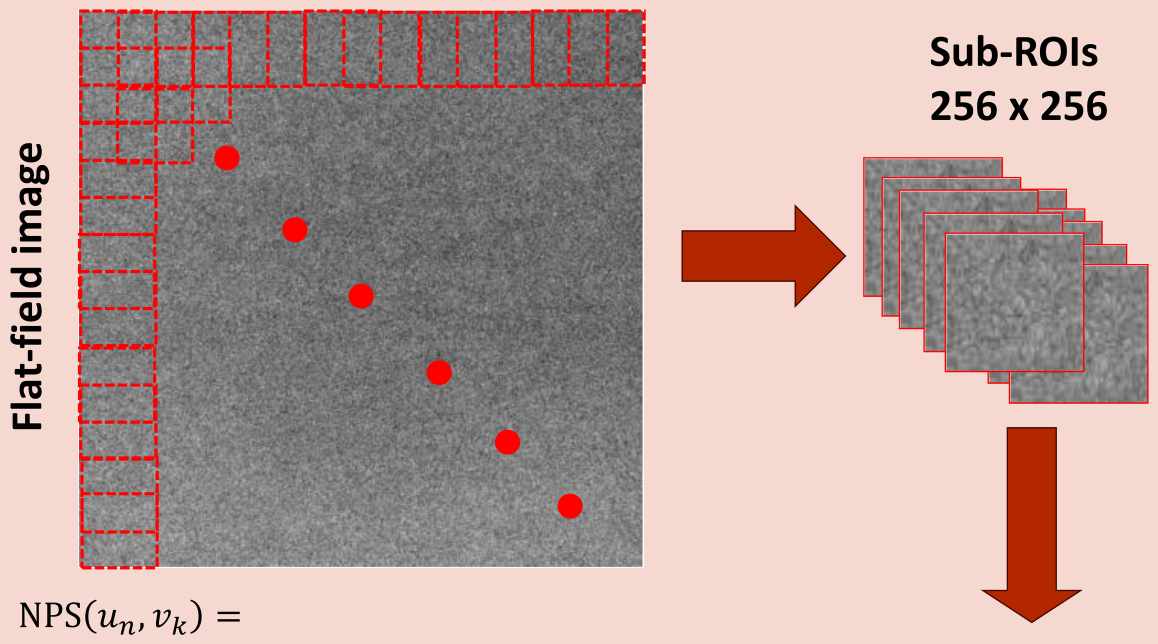
	IEC (Fig. 1)	Tech QC (Fig. 2)
kVp	70	
SID [cm]	120	100
Phantom	RQA5	3.8-cm Al
Phantom Location	On collimator cover	On patient table
Cu filtration [cm]	0.0	0.1
Detector Grid	Removed	In place

Table 1. Flat-field acquisition parameters used in this study.

Figure 1. Flat-field image setup with RQA5 phantom and detector grid removed.

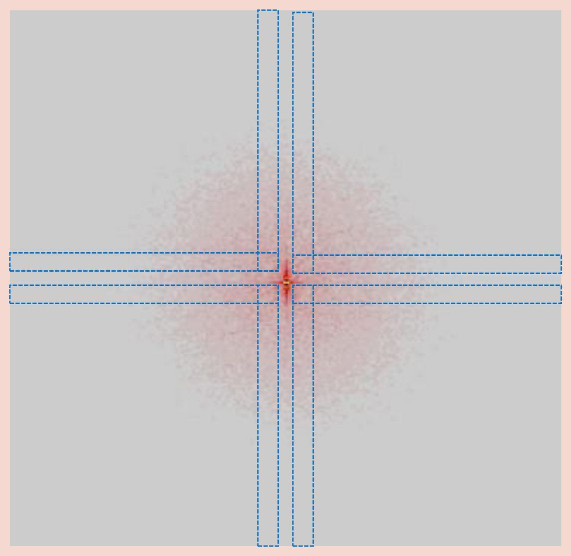
Figure 2. Flat-field image setup for IR technologist QC program.

THE NOISE RESPONSE METHOD

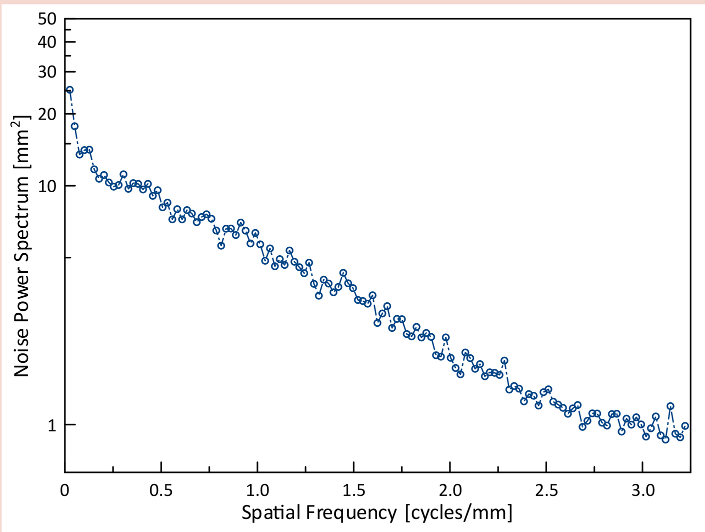


$$NPS(u_n, v_k) = \frac{\Delta x \Delta y}{M \cdot 256 \cdot 256} \sum_{m=1}^{M} \left| \sum_{i=1}^{256} \sum_{j=1}^{256} [I(x_i, y_j) - \bar{I}(x_i, y_j)] \exp\{-2\pi(u_n x_i + v_k y_j)\} \right|^2$$

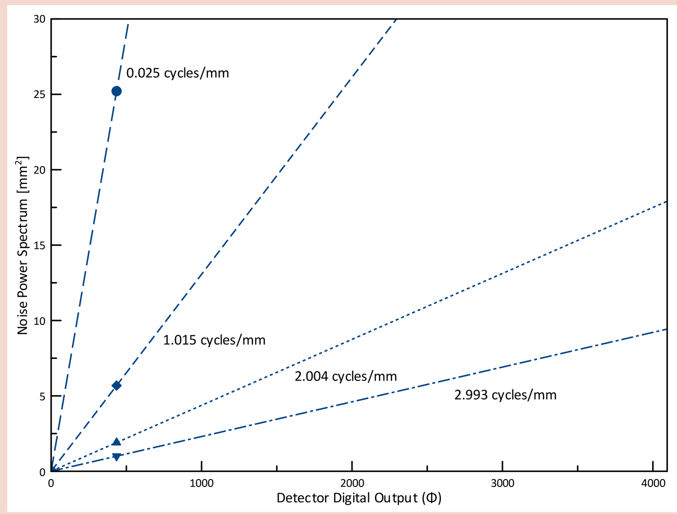
2D NPS



1D NPS



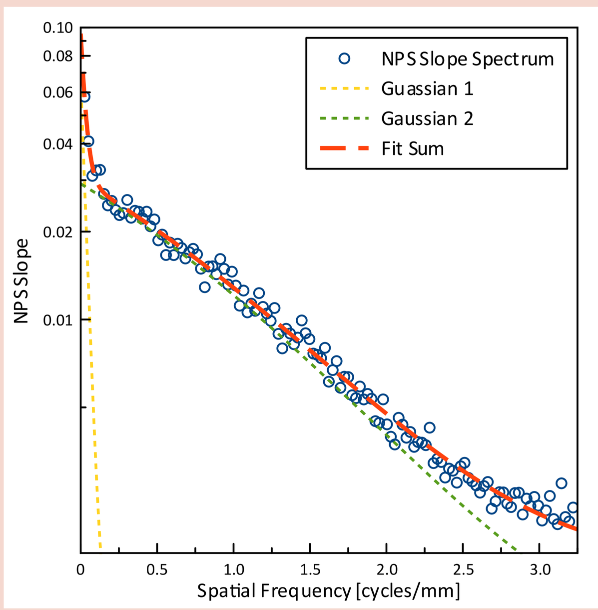
NPS versus Detector Signal (simplified method via [5])



Noise Response method [3]:

$$\boldsymbol{NPS(f,X)} = \underbrace{[\boldsymbol{K(f,X)} \times \boldsymbol{MTF^2}]\boldsymbol{\Phi(X)}} + \boldsymbol{NPS_{Sec}(f,X,X^2)}$$

NPS Slope Spectrum

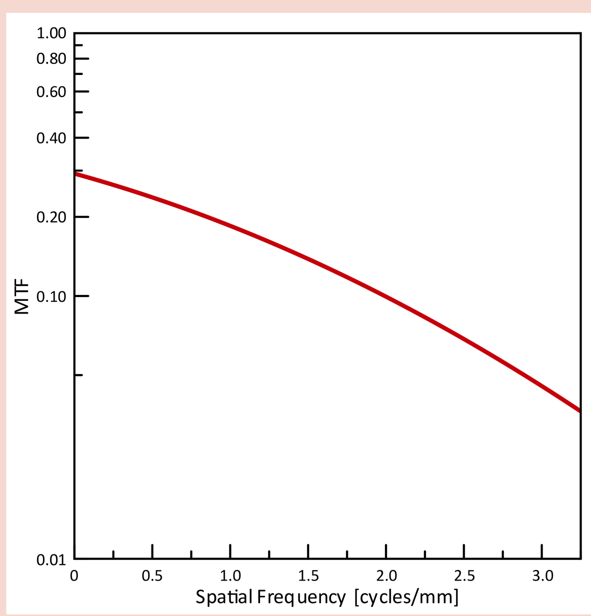


Mixed-Gaussian model fit

$$F(f) = \frac{h_1}{A_S(f)} \left[\sum_i^N h_{2_i} \exp\left\{ -\frac{(f - h_{3_i})^2}{h_{4_i}} \right\} \right]^2 + h_5$$

System MTF

$$\mathrm{MTF}(f) = \sum_i^N h_{2_i} \exp\left\{ -\frac{(f - h_{3_i})^2}{h_{4_i}} \right\}$$



OBSERVATIONS

The use of automatic exposure rate control and dose-level-independent image presentation in fluoroscopy provides challenges in application of the NR method. Nevertheless, preliminary results indicate that detector MTFs can be approached through use of a two-Gaussian fit to the NPS slope data to try to account for low-frequency structure noise and/or detector gain variations. Comparing NR-derived MTFs for RQA5 images and proposed technologist QC images (Figure 3) show some of the effects image post-processing has on standard acquisition protocols. Determining additional sources of image post-processing, as well as means of reducing the influence of secondary sources of detector noise (e.g., acquiring fluoroscopic "dark field" images) is ongoing to provide more robust flat-field fluoroscopy images to apply the NR method.

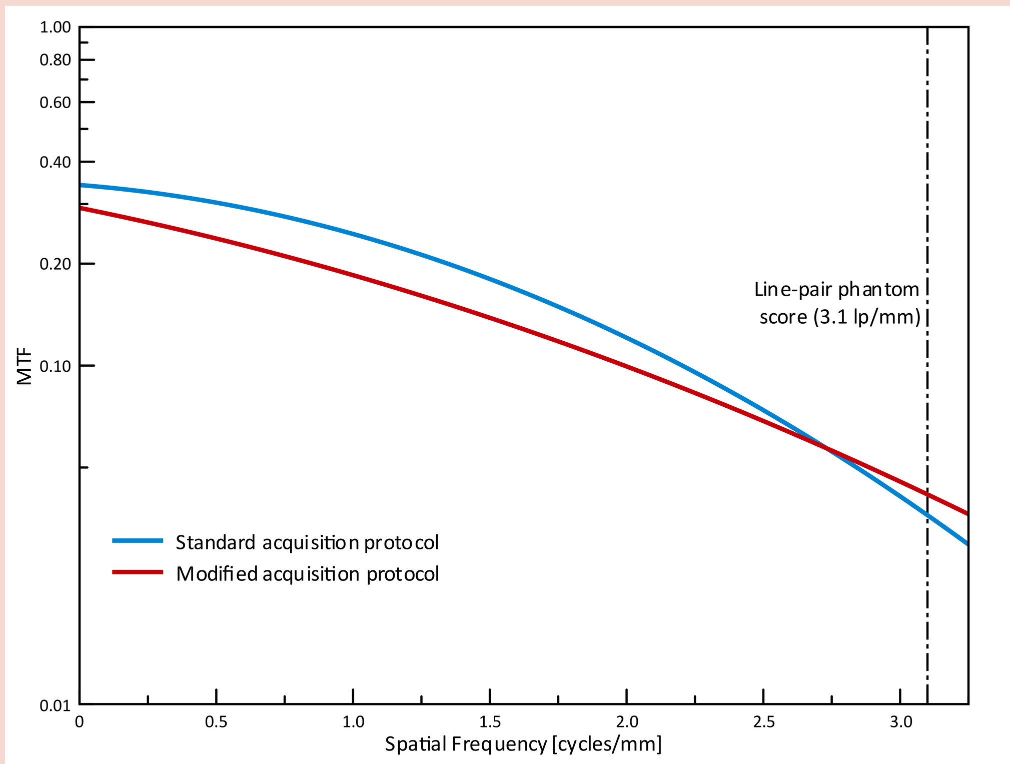


Figure 3. MTFs derived from standard and modified acquisition protocols, with typical spatial resolution from line-pair phantom for comparison.

CONCLUSIONS

A feasibility study for applying the NR method as part of an IR QC program was initiated. Detector flat-field images were obtained and processed via a Python script implementing the NR method. The IEC-derived NPS and resulting MTF could be appropriate as part of a medical physicist's acceptance testing of IR fluoroscopic systems for benchmarking purposes, with a more streamlined process for IR technologists used for system spatial resolution consistency checks that can be implemented as part of daily IR QC.

REFERENCES

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