Feasibility of an Analytical Medical Image Quality Assessment That Requires No User Input

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1. INTRODUCTION

To date, there is no gold standard for medical image quality assessment. Commonly used assessment methods are influenced by either manual selection or the algorithmic driven automatic selection of a Region of Interest (ROI).[1-4] An ROI is used in measurements of the signal mean, signal standard deviation and the system response such as an Edge Spread Function. Noise, artifacts and the user's selection of a ROI can affect the interpretation of the system's response.[1,2] Challenges in image quality assessment are more prominent when dealing with imaging systems with poor Signal to Noise Ratio (SNR).[5]

The conventional methods require the acquisition of a high exposure image to evaluate the imaging system in terms of metrics such as the SNR and Modulation Transfer Function (MTF). However, imaging systems such as Positron Emission Tomography (PET) are characterized by poor SNR, which makes image quality assessment tasks challenging and may require smoothing of the data used to execute the assessment. Smoothing can cause the loss or distortion of information.

2. AIM

This research aims to develop and evaluate the feasibility of an analytical medical image quality assessment that requires no user input.

The goal is to improve the accuracy and precision of assessment, especially for poor SNR imaging systems.

This method is intended for the quality assessment of imaging systems during design, commissioning, and routine quality assurance.

3. THEORY

The output of an imaging system can be predicted if the input and the characteristics of the system are known, using the formula

$$\dot{g} = h \otimes f + \dot{n}$$

$\dot{g}$: a unique realization of the output
$\otimes$: circulant convolution operator
h: the system response function
f: the input
$\dot{n}$: a unique realization of the noise

Note: this formula is valid under the assumption of a linear and shift invariant imaging system.

4. METHOD

The approach estimates image degradation factors, applies them to the known object in the image and compares the output with the test image.

The comparison is executed in the histogram space, removing the spatial dependence present in ROI-based methods.

As a feasibility study, planar x-ray imaging was chosen as a medical imaging technique that does not require image reconstruction and can be assumed to be quantum noise limited.

The method was tested using Monte Carlo simulated planar images of a simple disk phantom.

Since the SNR is a limiting factor of the ability to measure a system's performance, image quality assessment was carried at varying SNR levels.

The method's accuracy and precision were compared to conventional methods of image quality measurement.

5. METHOD SUMMARY

INPUT
Monte Carlo simulated test image

Optimization problem
Fit a parameterized model function to the input image cumulative histogram using 'Ferret' evolutionary optimizer from Qubist Global Optimization Toolbox for MATLAB (Jason D. Fiege, Ph.D., nQube Data Science Incorporated, 2010).

OUTPUT
Set of parameters that minimize the optimization fitness function

Calculate quality measures
MTF, SNR, Modulation contrast

6. RESULTS

As expected, the SNR level limited the ability to accurately and precisely measure the quality parameters using a cumulative histogram fit. Figure 1 shows the cumulative histograms at varying SNR levels, simulated using a 4 mm focal spot source (similar results were achieved for 10^{-5}, 0.3, 0.6, 0.9, 1.2, 2 and 3 mm). The actual and estimated image quality parameters associated with these cumulative histograms are presented in Table1. As the SNR level decreases, the noise degradation in the disk and background affects the shape of the cumulative histogram overriding the blurring degradation effect, and the number of data points used in the fitting process decreases (Figure 1).

The fit of the proposed cumulative histogram model to test images was affected by the inverse square increased attenuation, and the dose fall-off at the edge of the field of view. The best results were achieved with SNR values of at least 11.0 (+0.3, -0.2). For these levels, an average error in the signal and noise measurements of no more than 0.1 (+0.1, -0.1) % was obtained, while the average error in the measurement of the resolution was 0.1 (+0.2, -0.1) cycle/mm.

*Figure 1. Cumulative histograms for images of a 5 cm radius, 0.1 mm thick, lead disk in vacuum at varying SNR levels, simulated using a 4 mm focal spot, 40 keV monoenergetic photons source in BEAMnrc Monte Carlo simulation system. *error bars are too small to be seen and therefore not included.*

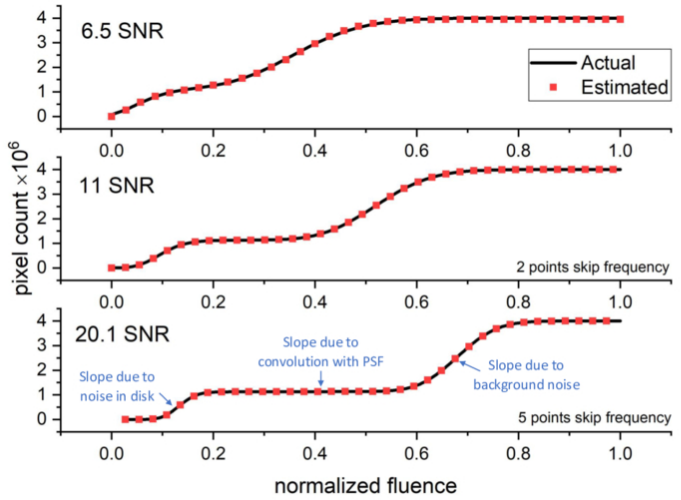

Table 1. Actual and estimated image quality parameters for a 5 cm radius, 0.1 mm thick, lead disk in vacuum at varying SNR levels.

SNR	6.5		11		20.1	
Parameter	Actual	Estimated	Actual	Estimated	Actual	Estimated
Noise factor	10000	6200 (+700, -600)	10000	10000 (+0, -100)	10000	9990 (+40, -30)
Fluence at Background (1/cm²)	133642	141000 (+3000, -2000)	387221	388000 ± 400	1264467	1267200 ± 200
Fluence at Disk (1/cm²)	16079	16000 ± 2000	77575	77600 (+200, -500)	253561	253600 (+100, -200)
MTF 10% (cycle/mm)	1.80	0.04 ± 0.01	1.80	2 (+2, -1)	1.80	1.9 ± 0.2
Disk radius (cm)	5.00	5.41 ± 0.06	5.00	5.001 (+0.007, -0.005)	5.00	5.001 (+0.001, -0.001)

7. CONCLUSIONS

This research developed and evaluated the feasibility of an analytical medical image quality assessment that requires no user input.

For images with an SNR of less than 10 (or less than 20 dB), the results were less promising and the error and uncertainty in noise and spatial resolution measurements were larger than conventional methods.

Therefore, despite the benefits of automation offered using this approach, further work is needed to enable this approach to be applied to low dose imaging systems.

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