Radiography: 2D and 3D Metrics of Performance Towards Quality Index

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Learning objectives

1. To understand methods for 2D and 3D resolution measurements.
2. To understand the basics for DQE and eDQE measurement techniques.
3. To relate physical metrics of performance to clinical image quality.

Outlook

- Medical imaging
  - clinically meaningful information
- Quality of information
  - image quality
- Image quality
  - universally-appreciated
  - universally-illusory
What is image quality?

• Image esthetics
  - Subjective and qualitative
  - Not necessarily reflective of diagnostic performance
• Diagnostic accuracy
  - Expensive
  - Impractical given the extent and variability of technologies

Physical metrics of image quality

• Convenient and practical
• Effective to the extent they can be related to diagnostic performance
• Applicable under qualified conditions:
  - Detector vs system
  - Incorporation of scattered radiation
  - Incorporation of anatomical attributes
  - Incorporation of task attributes
  - System-based vs image-based metrics

Resolution

• Ability to resolve distinct features of an image from each other

Resolution

• Best characterized by the modulation transfer function (MTF):
  - The efficiency of an imaging system in reproducing subject contrast at various spatial frequencies

\[ MTF = \mathcal{F}(LSF(x)) \]
Noise

- Unwanted signals that interfere with interpretation

Noise

- Best characterized by the noise power spectrum (NPS):
  - The variance of noise in an image in terms of the spatial frequencies

\[
ACF(x) = \frac{1}{\Delta x} \int \Delta i(x + x') \Delta i(x') dx'
\]

\[
NPS(f) = \Re\{ACF(x)\}
\]
Noise and Resolution $\Rightarrow$ SNR

- Threshold contrast and diameter $\sim 1/\text{SNR}$ (Rose model)
- Higher the SNR $\Rightarrow$
  Features with smaller C and D can be detected

\[
\text{NEQ}(f) = \text{SNR}_{\text{actual}}^2 = \frac{\text{MTF}(f)^2}{\text{NNPS}(f)}
\]
**SNR efficiency**

- Best characterized by the detective quantum efficiency (DQE):
  - Efficiency of a detector to utilize the maximum possible SNR provided by the finite number of x-ray photons forming the image

\[
DQE(f) = \frac{SNR_{\text{actual}}^2}{SNR_{\text{ideal}}^2} = \frac{MTF(f)^2}{NNPS(f) \times E_0 \times q}
\]

**Measurement method**

- Beam quality and magnitude
  - kVp
  - Filtration
  - Exposure
- Access to linear or linearized data

**Al purity**

- IEC recommendation: >99.9% purity

RQA5, 99.0% purity
RQA5, 99.99% purity

Ranger et al, Med Phys, July 2005

**Aluminum versus Copper**

Murphy et al, AAPM/COMP 2011
MTF methodology: Edge

- Edge test device
- ESF deduced from image data
- MTF from ESF via differentiation and Fourier trans.
- High precision, particularly at low frequencies
- Simple and quick alignment
- Established method (endorsed by the IEC)

Edge image processing

1. Finding the edge angle
   - Least square fits
   - Differentiation and Hough or Radon transform

2. 2D projection to obtain ESF
3. ESF differentiation and smoothing to obtain LSF
4. Fourier transformation of LSF to get the presampled MTF
5. Normalization of the MTF at 0 frequency
6. Rebinning the MTF (0.05 mm⁻¹ per IEC)

railabs.org/resources
Effect of method (GE XQ/i)

Diffs <6% overall
<8% single f

Effect of method (ideal)

Diffs <0.3% for slit
<5.2% for edge

Effect of method (w/ glare)

Diffs <10% for slit
<2% for edge

DQE methodology

\[
DQE(f) = \frac{SNR_{actual}^2}{SNR_{ideal}^2} = \frac{MTF(f)^2}{NNPS(f) \times E_0 \times q}
\]

MTF => Measured
NNPS => Measured
\( E_0 \) => Measured
\( q (SNR_{ideal}/E_0) \) => Estimated
Adding magnification, scatter, grid

\[ DQE(f) = \frac{SNR^2_{\text{actual}}}{SNR^2_{\text{ideal}}} = \frac{MTF(f)^2}{NNPS(f) \times E_0 \times q} \]

\[ eDQE(f_m) = \frac{eMTF(f_m)^2 \times (1 - SF)^2}{eNNPS(f_m) \times TF_{nb} \times E_0 \times q} \]

Samei et al., Med Phys., 2009
From DQE to IQ

Resolution and contrast transfer

Attributes of image feature of interest

Image noise: magnitude and texture

\[ d'^2 = eDQE(f_m)W(f)^2 fdf \]

Model observers

Fisher-Hotelling observer (FH)

\[ (d_{FH}^2)^2 = \frac{MTF^2(u,v)W_{task}^2(u,v)}{NPS(u,v)} \]

Non-prewhitening observer (NPW)

\[ (d_{NPW}^2)^2 = \frac{MTF^2(u,v)W_{task}^2(u,v)}{MTF^2(u,v)W_{task}^2(u,v)NPS(u,v)du dv} \]

NPW observer with eye filter (NPWE)

\[ (d_{NPWE}^2)^2 = \frac{MTF^2(u,v)W_{task}^2(u,v)NPS(u,v)E^2(u,v)}{MTF^2(u,v)W_{task}^2(u,v)NPS(u,v)du dv} \]

Validation of model observers

Richard, Li, Samei, SPIE 2011

eDQE applied to acquisition optimization

Boyce et al, Med Phys, 2005
From DQE to IQ and dose: Effective Dose Efficiency (eDE)

$$eDE(f_m) = eDQE(f_m) \cdot q \cdot \frac{E_S}{ED} \cdot \frac{SSD}{SID}^2$$

Summary

- MTF can be robustly measured using edge method
- DQE provides a meaningful measure of detector performance correlated with human performance
- DQE can be readily extended to system performance (via eDQE)
- DQE can readily be normalized by dose (eDE) for acquisition optimization