Quality advances via noise reduction in laser imaging*

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Abstract

Purpose

Noise sources in medical imaging and printing can limit diagnostic accuracy but are often not assessed quantitatively. A method is described for objectively quantifying noise by means of a film digitizer and analysis software. A second method, based on human perception of simulated nodules on films with varying amounts of noise, is also described.

Methods and Materials

In the first method, a film digitizer scans a print of a constant gray level image. The scanned digital image file is then processed by software that: (1) extracts and averages density data from narrow horizontal and vertical strips, and (2) performs one-dimensional Fast Fourier Transform (FFT) processing to yield a Noise Power Spectrum (NPS) for each horizontal or vertical strip. In the second method, a computer program is used to synthesize a test image with very low contrast dots ("nodules") superimposed on a gradually changing background. In timed experiments, prints of these images are placed on a light box, and an observer is asked to mark the locations where the dots are believed to be present, after which the true and false positives are counted.

Results

Prints were made on a variety of medical imagers, using film with a variety of quality levels. Prints made with the latest laser imager and film yielded lower measured noise and higher perception scores than prints made with prior technology.

Conclusion

Measurable progress has been made in reducing the noise level of medical imaging printers. This is further demonstrated by improved perception of subtle details.

About the Author

Thomas R. Lindquist is a Senior Imaging Scientist in Kodak's Health Imaging Group, analyzing systems such as laser imagers and developing methods, algorithms and software to quantify and optimize their performance. Previous experience includes extensive work in the areas of imaging algorithms and software development for medical imaging systems. He has contributed to the NEMA Grayscale Display Function Standard and is a member of the American Association of Physicists in Medicine (AAPM) and the Institute of Electrical and Electronic Engineers (IEEE). He received his doctorate in physics from the University of Minnesota.

Purpose

Noise sources in medical imaging and printing can reduce diagnostic accuracy, but are usually not assessed quantitatively. Today's common practice of placing a test film on a light box and assigning a quality level to it based on its visual appearance is inherently subjective and imprecise.

The first method described here addresses the need to measure noise objectively. Noise is quantified by means of a film digitizer[*1] and analysis software[*6A, *6B].

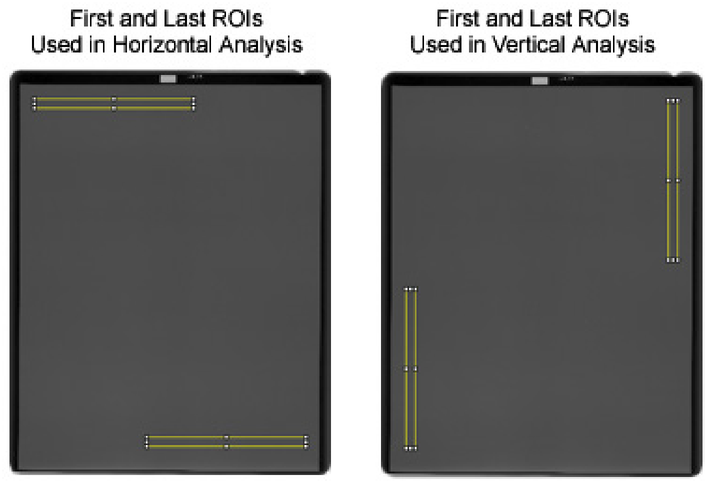
A second method, based on human perception of simulated low-contrast nodules[*4A, *4C] on films with varying amounts of noise, is also described here. This addresses the need to correlate the objective noise measurements with measured performance of human observers performing a visual detection task in the presence of the noise.

Methods and Materials

Method 1 Noise Power Analysis

In the first method, a film digitizer[*1] scans a print (e.g., from a laser imager) of a constant-valued (flat field or grayout) image. The scanned digital image file is then processed by software that: (1) extracts and averages density data from narrow horizontal and vertical strips[*2], and (2) performs one-dimensional Fast Fourier Transform (FFT) processing to yield a Noise Power Spectrum (NPS) for each horizontal or vertical strip.

1: LS75 film digitizer



2: First and last Regions of Interest strips

In the horizontal analysis pass, density variations along the film's horizontal (x) axis are analyzed. This analysis takes place using short, wide Region-Of-Interest (ROI) rectangles. Original pixels are averaged in the vertical (y) direction of the ROI, yielding a one-dimensional array of vertically averaged densities. To minimize the effect of a possibly gradually changing background density, this array is then modified by subtraction of a linear ramp, defined as a linear interpolation between the first and last values of the array.

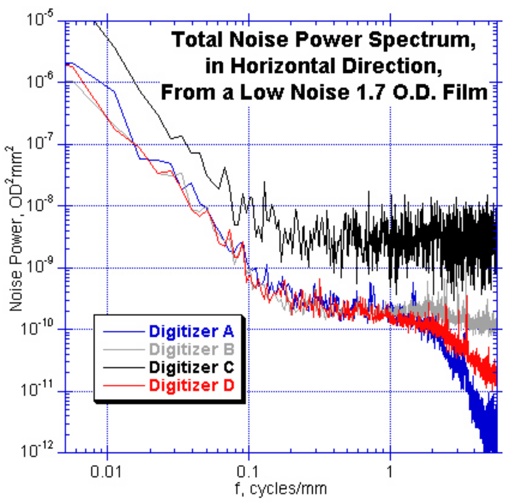
In the horizontal analysis done here, 3 overlapping horizontal ROI positions were used and 40 overlapping vertical ROI positions were used, giving a total of 120 ROI positions that were used. The vertical NPS analysis proceeds similarly, but using vertically oriented ROIs.

Before reviewing sample results from this method, it is important to note that the noise power spectra calculated here include the noise contributed by the film digitizer itself, which depends upon the type of digitizer which is used. At film optical densities above approximately 2.0, a digitizer which uses laser / photomultiplier tube technology will typically provide a better signal-to-noise ratio than CCD-based digitizers. But even a modest density (~ 1.7 O.D.) high quality grayout film can give very different noise values, depending on the digitizer used, the analysis direction, and the spatial frequency being considered.

Methods and Materials

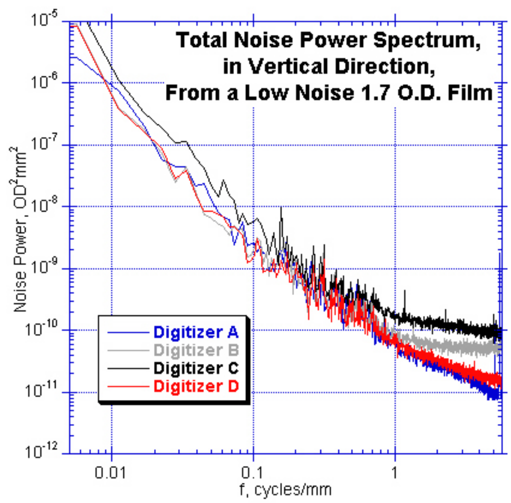
See, for example, the total NPS from four different digitizers*3A, *3B, all scanning a high quality (low noise) 1.7 O.D. film.

No attempt has been made here to isolate and subtract the noise contributed by the digitizer itself, which in general will depend both on the type of digitizer used and the settings of the digitizer. But provided that film digitization is always done in the same way (using the same good quality digitizer and settings), the total noise power spectrum as calculated here gives a useful, repeatable quantitative indication of relative film quality.



A: Laser/photomultiplier-based medical digitizer (Kodak LS-75)
B: Laser/photomultiplier-based drum digitizer
C: CCD-based consumer-oriented flatbed digitizer
D: CCD-based medical digitizer

*3A: Horizontal total NPS, using 4 different digitizers



A: Laser/photomultiplier-based medical digitizer (Kodak LS-75)
B: Laser/photomultiplier-based drum digitizer
C: CCD-based consumer-oriented flatbed digitizer
D: CCD-based medical digitizer

*3B: Vertical total NPS, using 4 different digitizers

It should also be noted that the digitized signal (i.e., true density fluctuations on the film), as well as the digitized noise, depend on the film digitizer which is used and may also depend on the analysis direction.

Because of its good signal-to-noise characteristics at the spatial frequencies of greatest interest here, the LS75 is the digitizer which has been used for the results reported throughout the rest of this paper.

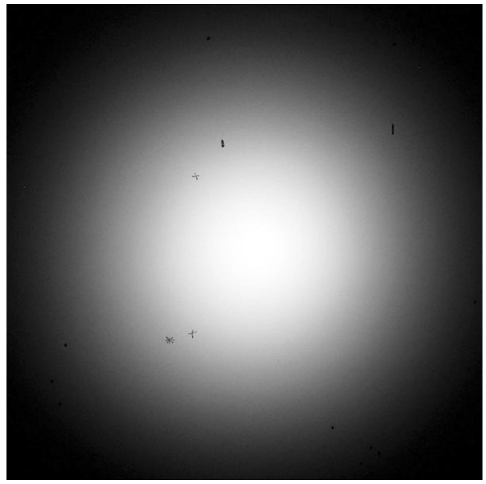
Method 2 Quantifying Low Contrast Perception

In the second method, a computer program was written to create a digital test image*4A with many very low contrast dots (nodules) superimposed on a gradually changing background (a "ball"). The contrast of these dots is subtle enough to require a wide dynamic range display (e.g., film on a bright light box) to see most of them. In timed experiments, prints of these images are placed on a light box, and an observer is asked to mark the locations*4B where the dots are believed to be present, after which the true and false positives are counted.

Methods and Materials

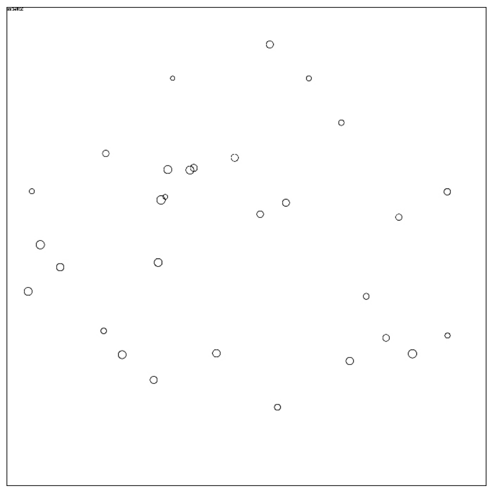
A variety of bright center and dark center 2048 x 2048 x 12-bit dots-on-ball images were generated, each containing 30 randomly positioned dots, with each dot having a random polarity (light or dark), random amplitude (between 0.2% and 0.6% of the full scale image pixel value) and random diameter (between 1% and 2% of the ball diameter). The edge of each dot is slightly tapered (over two pixels). An answer sheet *4C shows the true locations of the dots.

*4A: A dots-on-ball image. (Dots may not be evident on typical computer display screens.)



*4B: Marked dots-on-ball film

Many such images were then printed, using a perceptually linear grayscale lookup table on a variety of samples of 14x17 film, using a variety of medical imaging printers, including both photothermographic laser imagers and direct thermal printers.



*4C: Answer sheet for a dots-on-ball image

To compare an observer's ability to detect the dots on one print type vs. another, a set of four films was prepared for an individual reading session. These were read in the following order:

- A bright center print, using film / printer combination #1
- A dark center print, using film / printer combination #2
- A bright center print, using film / printer combination #2
- A dark center print, using film / printer combination #1

Each film had a different random dot pattern but all had the same statistical distribution of dot contrast and dot size.

Methods and Materials

The protocol for reading films begins with the observer being brought into a film viewing room equipped with a bright lightbox and excellent viewing conditions. An example training film is shown to the observer, along with a corresponding answer sheet for that film, to acquaint the observer with the type of objects which are to be visually detected. The observer is not asked to operate at any particular confidence level, but is asked to operate at a consistent level of confidence throughout the entire session. When the observer is comfortable with the task at hand, a series of timed runs begins, allowing a total of ten minutes to be spent viewing and marking each of the four films. A proctor is present to monitor the timing.

For each film, the observer marks, directly on the film, each position where he or she believes a dot is present. During the session, the proctor closely monitors the elapsed time and tells the observer when to switch from one marking symbol to another, in accord with the following arbitrary conventions:

Film Marking Conventions

Start Time (minutes:seconds)	End Time (minutes:seconds)	Marking Symbol to Use
0:00	1:00	.
1:00	2:00	|
2:00	5:00	+
5:00	10:00	*

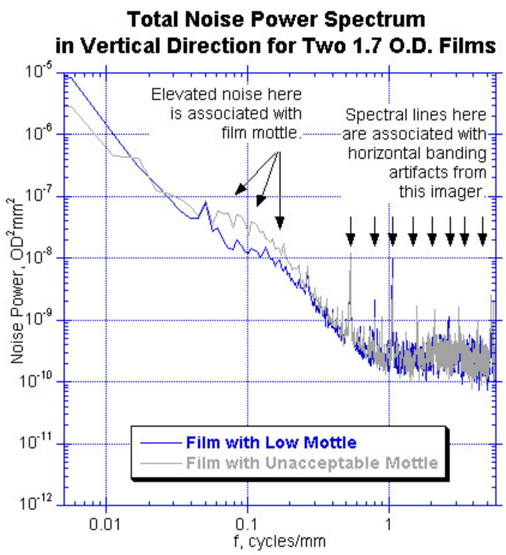
After a viewing session, the markings on its films are assessed by means of the answer sheet films which correspond to the films which were viewed in that session.

To graphically present the data from a viewing session, a "Temporal Receiver Operating Characteristic" (TROC) was defined. In essence, the TROC plots the cumulative measured true positive and false positive counts as functions of elapsed observation time, for each of the two film types that were used in a session.

Results

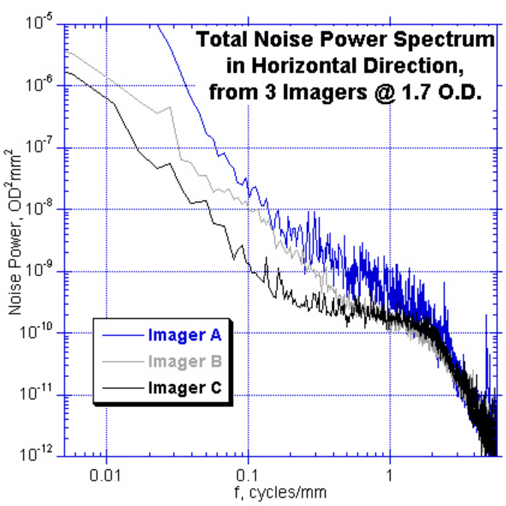
Results 1 NPS Applications

One application of the NPS analysis method is to quantify defects which previously were only estimated visually. For example, an NPS film quality assessment*5 was made of two 1.7 O.D. films, one of which had unacceptable flow mottle when assessed visually by film quality inspectors. In this comparison, the film with the unacceptable flow mottle has measurably greater noise in the low-to-mid frequency portion of the NPS.



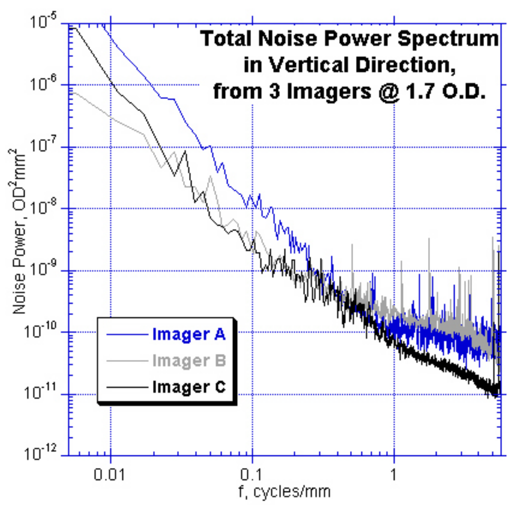
5: NPS example showing effects of mottle and banding

A second application of the NPS analysis method is to compare the quality of films printed by various imagers*6A, *6B. For example, the NPS below were obtained from three 1.7 O.D. films printed by three currently available medical imagers, all digitized on an LS75 digitizer. At low-to-mid spatial



A: A 320 ppi direct thermal imager
B: A 508 ppi laser imager
C: A 650 ppi laser imager (Kodak 8900 with V. 3 film)

**6A: Horizontal NPS from 3 imagers*



A: A 320 ppi direct thermal imager
B: A 508 ppi laser imager
C: A 650 ppi laser imager (Kodak 8900 with V. 3 film)

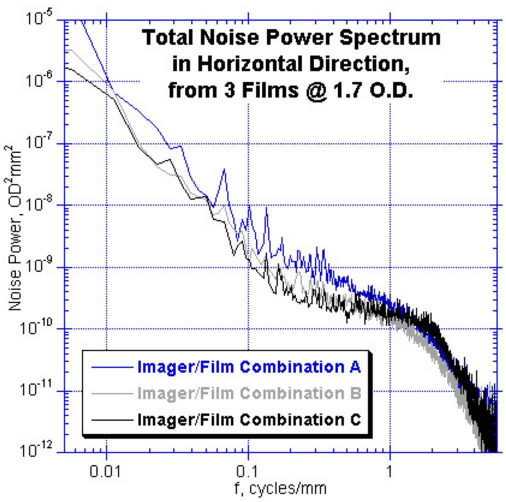
**6B: Vertical NPS from 3 imagers*

Results

frequencies, the noise from the direct thermal imager film was highest in both analysis directions. Through nearly all of the spatial frequency range analyzed here, imager C gave the lowest measured noise in both analysis directions.

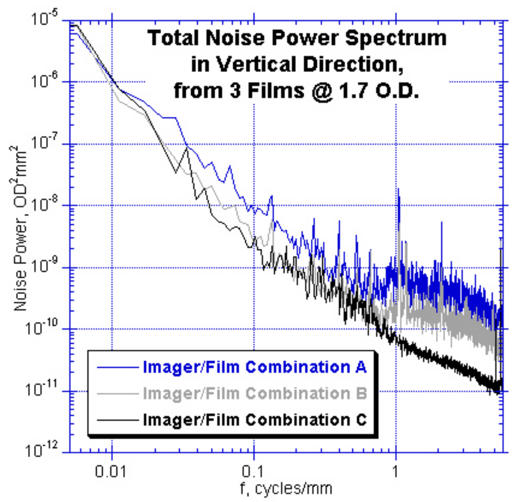
As a third application of the NPS analysis method, product development engineers can separately assess incremental noise reductions[*7A, *7B] due to various improvements in film and imager technology.

These spectra demonstrate that some noise reduction resulted from film improvements and that further noise reduction resulted from imager improvements.



A: Kodak 8700 imager with Version 2 film
B: Kodak 8700 Imager with Version 3 film
C: Kodak 8900 imager with Version 3 film

**7A: Horizontal NPS showing imager/film improvements*



A: Kodak 8700 imager with Version 2 film
B: Kodak 8700 Imager with Version 3 film
C: Kodak 8900 imager with Version 3 film

**7B: Vertical NPS showing imager/film improvements*

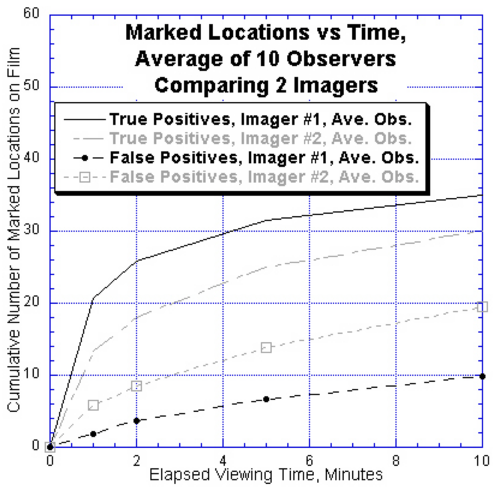
Results 2 - Perception Studies

Films of dots-on-ball patterns were printed on each of two imager/film combinations: an older 8700 imager with V. 2 film and the current 8900 imager with V. 3 film. The 8900 was allowed to use its higher maximum density setting. (For these prints, the maximum density settings used were 3.0 for the 8700 and 3.3 for the 8900.)

The printed films were organized into sets of four films each (two films from each of the two imager/film combinations). Each set of four films was subsequently viewed and marked by one observer.

Results

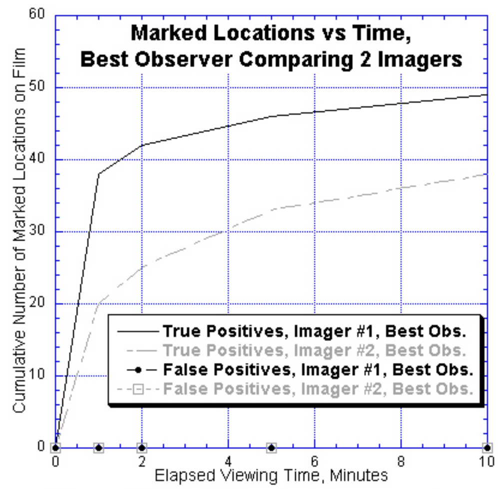
Averaging the counts of true positives and false positives from ten observers yields the average observer curves*8. Using only the data from the best observer (defined here as the observer with the highest combined count of all true positives) yields the "best observer" curves*9, which show an even stronger improvement in score associated with the latest imager / film combination.



Average "Temporal ROC" plots from ten observer sessions, each comparing prints from two imager/film combinations:

Imager #1: Latest imager and film (Kodak 8900, V. 3 film)
Imager #2: Earlier imager and film (Kodak 8700, V. 2 film)

**8: Average "Temporal ROC" plots from 10 observers*



"Temporal ROC" plots from best observer session, comparing prints from two imager/film combinations:

Imager #1: Latest imager and film (Kodak 8900, V. 3 film)
Imager #2: Earlier imager and film (Kodak 8700, V. 2 film)

**9: "Temporal ROC" plots from best observer*

These curves demonstrate that prints made with the latest laser imager and film yielded higher perception scores (more true positives and fewer false positives) than prints made with prior technology imager / film combinations.

Conclusion

Progress has been made in reducing the noise level of medical imaging printers. This has been demonstrated quantitatively as reduced levels of the Noise Power Spectra calculated from digitized films of constant gray-value images.

This reduction of the noise in the printed film may contribute significantly to the observed speed and correctness of human observers in detecting and locating low amplitude (0.2% - 0.6%) features on prints of a noiseless digital test image.

For actual medical images, those which have the lowest intrinsic noise can be expected to benefit most from the reduced noise printing.

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A special note of appreciation goes to all who took part in the perception studies reported here.

Keywords

Own Keywords:
noise, perception, ROC, film, digitizer, imager, printer, quality

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