The Association Of Radiographers Of Nigeria
EYE OF MEDICINE

JOURNAL OF THE ASSOCIATION OF RADIOGRAPHERS OF NIGERIA

ISSN: 1115- 7976 Vol 31, Issue 1, November, 2017

The Official Journal of The Association of Radiographers of Nigeria

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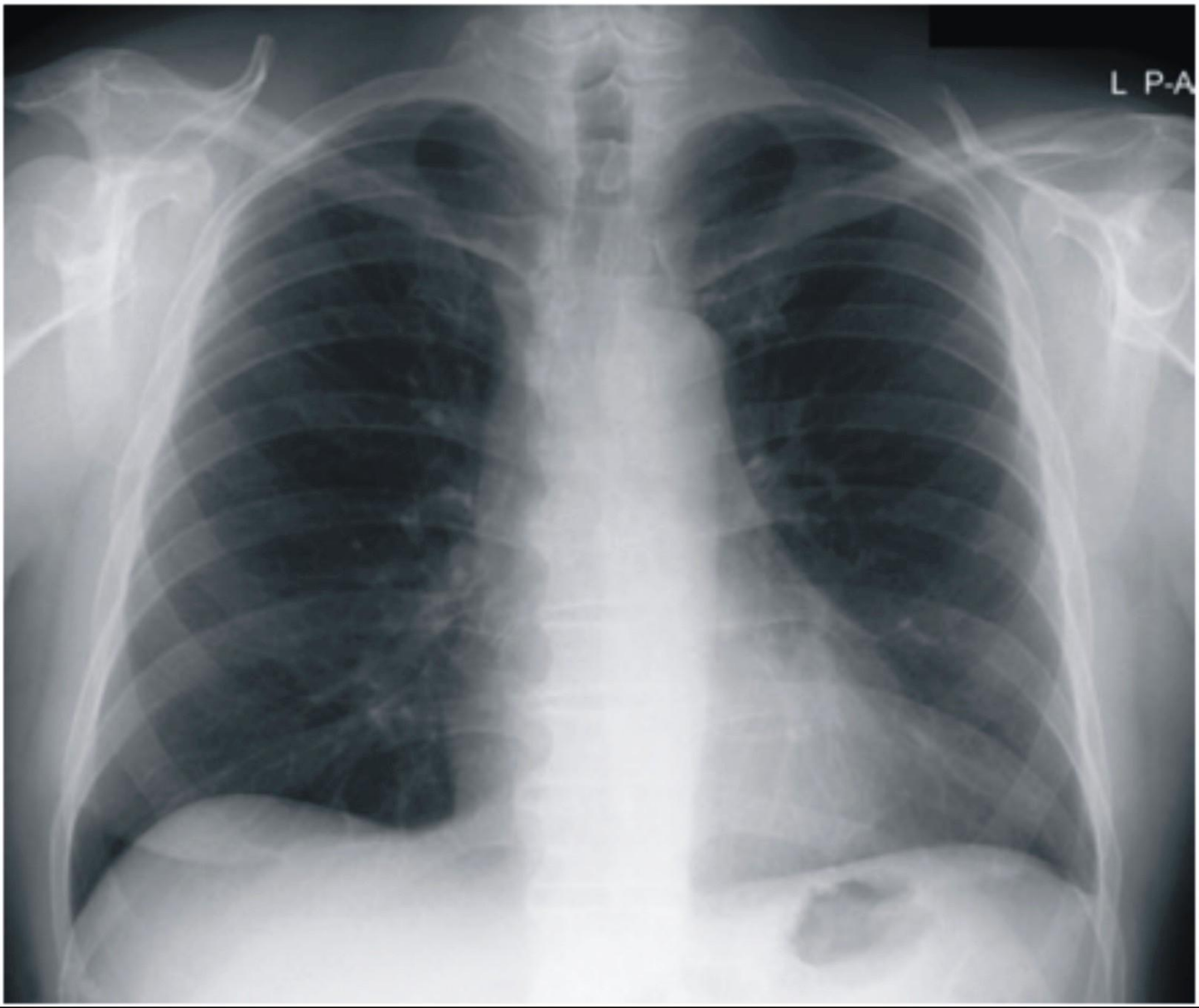

Journal homepage: www.jarnigeria.com

Understanding Radiographic Image Noise Measurement and Removal

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Received: 4 April, 2017. Received in revised form: 2 August, 2017. Accepted:14 October, 2017

ABSTRACT

Background: The radiographic image is characterized by image noise arising from random fluctuations in the absorption of photons by the imaging medium or detector. Measurement and removal of these perturbations will increase the quality of the signal which is desired in improving image interpretation.
Purpose: This paper is a short review to improve understanding of the phenomena.
Method: A review of some literature was undertaken to facilitate improved appreciation of noise and its measurement. Use of filters in the removal of image noise is covered the review.
Conclusion: An understanding of image noise and its contributing parameters is essential to the utilization of post processing techniques for improving image quality.
Keywords: Signal, Noise, Image quality, Radiographic, detection, spectrum

Introduction

Medical imaging has assumed a central position in the diagnosis and management of disease processes[1]. The ability of radiologists to visualize and interpret image features depend on the quality of the images produced. High quality images render disease processes visible and improve their detection and characterization[2-4]. The quality of a radiographic image is determined by many parameters involved in its formation, from acquisition to image reconstruction and post-processing through to display [5].

Radiographic image quality is characterized by contrast, resolution and noise[5, 6]. Contrast refers to the difference in optical density on the image and enables the distinction of image features. Resolution is the distinctiveness to which the details of an image can be seen, and determines the ability to visualize and resolve image information. Noise refers to undesirable image perturbations or fluctuations in optical density in a radiographic image that hinder the visualization of tissue parenchyma for features of disease. These fluctuations may be due to tissue superimposition (anatomic noise) and variations in the acquisition and display systems (radiographic noise) [6, 7].

In consideration of the relevance of image quality to diagnostic performance in radiology, it is essential that imaging technologies demonstrate the highest image quality, so as not to compromise diagnostic efficacy. Thus, information gathered by imaging modalities must be conveyed accurately without irregular fluctuations that will reduce visualization of the acquired information. To achieve this, there have been continuous technological advances in the acquisition and display components of the imaging chain[3, 8]. Newer imaging technologies have capabilities for post-processing contrast adjustment, resulting in image quality improvement[9]. However, the fast count rate of newer detector technologies increases the potential for noise. Radiographic noise is the most undesirable image quality parameter and limits the ability of radiologists to interpret radiographic images[4].

Noise degrades image quality through a reduction in contrast and resolution, and thus limits the diagnostic value of the image [4, 6]. The impact of noise is most prominent in high spatial frequency low-contrast object and soft tissue structures. Clinically, noise reduces the visibility and detection of soft tissue abnormalities and subtle lesions[4]. The negative impact of noise on diagnostic performance underscores the need to characterize noise of imaging systems and acquired images in order to explore ways of optimizing the imaging process. A reduction in noise will improve image information and allow radiologists visualize and interpret disease conditions in radiographic images. This review examines radiographic noise, methods of noise measurement, and ways of removing image noise.

Radiographic image noise

Every radiographic image contains some level of noise, however the magnitude varies. A single straight linetrace through a homogenous area on a radiographic image may show fluctuations in pixel values within the area, representing the noise in that image[10, 11]. Similarly, when a cursor is moved across a homogenous structure such as water, which has a CT number of 0 Hounsfield Unit (HU), the same CT number (HU) is expected.However, the CT number fluctuates usually between -1 to +2 as the cursor is moved through the homogenouslywater filled structure.

This fluctuation in CT number on a homogenous region of CT image represents the range of pixel intensities within the region.The standard deviation of the CT number is degree of noise and presents as graininess or mottle in that image[11].Graininess reduces the visibility and resolvability of image features and is determined by standard deviation of pixel values in that image[11]. The standard deviation (noise) is given by:

$$\sigma= [\Sigma\ (CT_i - CT_{mean})^2 / (n-1)]^{1/2} \qquad (1)$$

X-ray beam contain a stream of independent photons with varying wavelengths. These photons are detected to varying degrees by the image receptor, and their disproportionate distribution on the detector appears as noise in the image. The magnitude of noise depends on the randomness of the distribution of the X-ray photons on the image. In planar radiography, image noise is determined by the number of photons absorbed b the detector (intensifying screen) and is related to individual pixels that make up the image [11, 12].

High detective quantum efficiency (DQE) detectors require less exposure to produce an image. The reduction in X-ray exposures reduces the number of photons absorbed by the detector, and results in higher image noise. Thus, factors that increase detector sensitivity (speed) such as detector composition and thickness as well as X-ray spectra influence image noise [11].

The amount of noise in CT images depends onthe number X-ray photons measurement by the detector and is determined by imaging parameters [11]. The higher the number of photons measured, the lesser the noise of the resultant image. Consequently, factors such as tube current (mA), scan time, slice thickness, and tube potential (kVp) that reduce the number of photons measured by the detector increase CT image noise[11, 12]. Tube current (mA) controls the intensity of the radiation beam and the number of photons that can be measured by the detector. Tube current is directly related to the number of photons in the beam, and higher mA is associated with lower image noise, but higher radiation dose.

Variations in scan time are associated with differences in the detector measurement durations, with longer scan durations associated with higher number of detected photons and thus lower image noise. Slice thickness is directly related to the diameter of the beam and thus the number of photons reaching the detector. With thicker slices, a greater number of photons are measured by the detector, resulting in lower image noise [13]. The number of X-ray photons transmitted through the patient and measured by the detector is directly related to the tube potential. Therefore, higher kVp reduces image noise, but has a negative impact on subject contrast.

In summary, noise in CT images result from limited number of X-ray photons measured by the detector, and arises mainly from poor exposure parameter selection [11-13].Because radiographic noise has varying effects on the contrast and resolution of objects of different spatial frequencies, it is commonly described by noise power spectrum (NPS) [11].

The NPS is the ratio of noise in the image and the spatial frequencies within the image. Two quantities are used to describe the noise in a radiographic image and include relative and absolute noise. Relative noise (normalized noise power spectrum [NNPS])impedes the visualization of tissue features on an image and thus the detection and characterization of soft tissue lesions. It describes the extent of photon fluctuation relative to the signal present in the image. The absolute noise (noise power spectrum [NPS])describes the absolute degree of photon fluctuations within the image [11, 12]. It is an indicator of the noise transfer characteristics of the imaging technology, and does not account for the impact of noise on image contrast and resolution.

Measurement of noise

As discussed previously, noise manifests as fluctuation in the correlation properties of a radiographic image or fluctuation in CT number of a homogenous structure. The amount of fluctuation in an area of interest provides a measure of the noise present. The noise in an image can be assessed qualitatively and quantitatively. Qualitative assessments involve visual inspection and rating of the noise in a radiographic image by observers. This is a subjective approach and is prone to inter-observer variability[14].

Quantitative measurement provides an objective estimate of the noise in a radiographic image and is discussed in this paper. Digital systems have a function that allows for a Regions of Interest (ROIs) measurement. To measure noise, the function is used to place an oval or rectangular ROIs on the image as shown in Figures 1A and 1B.

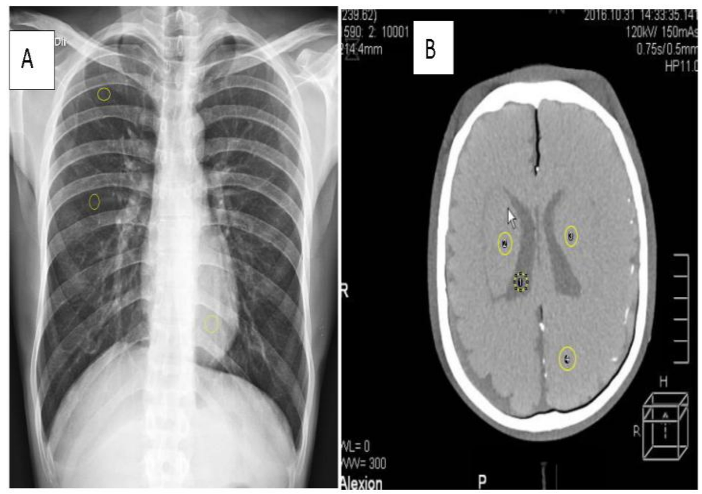

Figure 1: Regions of Interest (ROIs) selection for noise measurement. A: chest X-ray, B: Cranial computed tomography scan. The noise from the selected ROIs can be averaged and used to characterize the noise in the image.

Any location can be selected for noise measurement as long as it is within a homogenous structure. However, because high spatial frequency and low contrast structures are mostly affected by noise, measurements are mostly made from regions in such structures. Within these ROIs, the automatically calculated average and standard deviation (SD) for the encircled pixels will appear. The SD indicates the magnitude of random photon fluctuations and provides a measure of noise in the image [11]. The larger the standard deviation, the higher the noise present in that image. The impact of different noise levels on image quality is shown in Figures 2.

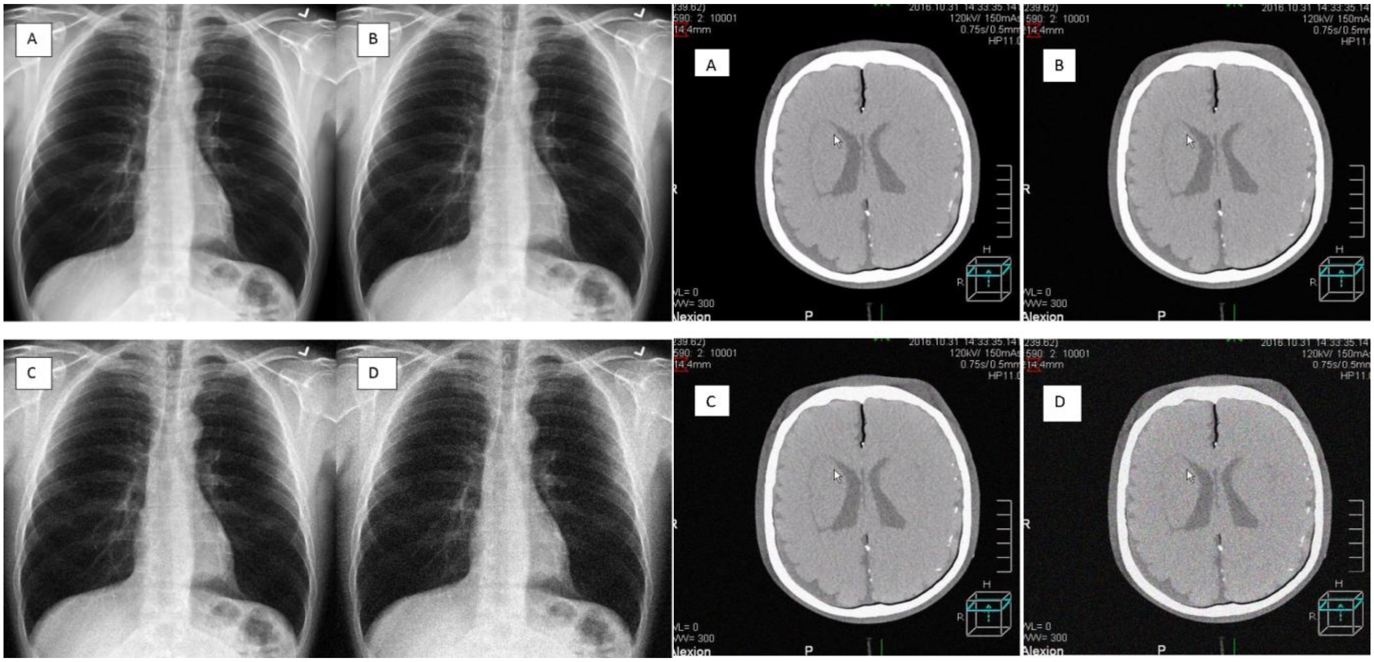

Figure 2: (A) Chest X-ray and (B) CT images with varying magnitudes of noise. In both cases, the image labeled A is the original image whilst B, C, and D represent images with added noise. The noise levels (SD) are 5, 10, and 20 in images B, C, and D respectively on both the chest X-ray and CT images. As the noise levels increases, the images become grainier

Since structures of different spatial frequencies or inherent contrast are differentially affected by noise, it is important to measure noise in different regions of the image. ROIs may be selected from different homogenous structures and the noise levels from these ROIs averaged to characterize the mean noise of the image. The absolute noise (NPS) should be used to characterize and compare the noise generated by different imaging systems. Such comparisons will allow for assessment of the comparative performance characteristics of these systems. Reconstruction algorithms and filter also influence image quality and dose. Filters harden the radiation beam and improve image resolution; however, increased filtration increases image noise [15].Thus, the noise generated by different reconstruction algorithms and filters can be measured and compared to identify the appropriate parameters for optimization purposes. In this case, it might be necessary to measure both the NPS and the NNPS to assess the impact of the noise on image quality.

Signal-to-noise ratio (SNR)

The impact of noise on image quality can be quantified by its effect on the visibility of image features [4,5,12]. This can be assessed by measuring the normalized noise power spectrum (relative noise) or signal-to-noise ratio (SNR). In other words, the level of contrast in a radiographic image depends on the ratio of signal to noise from the imaging system. Because the impact of noise on image contrast depends on the spatial frequency of the structure, SNR can be calculated as shown below.

$$\mathbf{SNR = CAQ} \sqrt{} \;\ldots\ldots\ldots\ldots\ldots \qquad \mathbf{(2)}$$

where SNR: signal-to-noise ratio, C: object contrast, A: object area, Q: Number of photons per unit area.

Since the number of quanta per unit area cannot be quantified in a processed image, the signal intensity in that image and its standard deviation is used to calculate the SNR.

It is calculated in an image as the ratio of signal intensity [SI] in ROIs and the standard deviation [σ] of the signal intensity in these regions [6, 11].

$$\mathbf{SNR = SI/\sigma} \qquad \mathbf{(3)}$$

A good quality, high contrast image should demonstrate a SNR ratio greater than 1.0, indicating that the signal is stronger than noise, with higher values denoting the better image quality. A SNR less than 1.0 indicates that the noise is greater than the signal, meaning that the image is of poor quality.

As described earlier, structures of different spatial frequencies or inherent contrast are differentially affected by noise. Consequently, SNR measured from different structures within an image would vary considerably. Radiographically, the distinction of image features depends on the level of contrast in that image. Images with a high SNR may have low contrast-to-noise ratio (CNR), which may limit the detection of abnormalities. Such limitation emphasizes the need to also characterize the quality of a radiographic image using CNR in order to assess image contrast degradation due to noise. CNR refers to the variation in signal intensities of two ROIs relative to the background noise. CNR can also be expressed as the different in SNR between two ROIs as shown in the equations below. CNR is a parameter for assessing the quality of a radiographic image and not a property of the imaging system [4, 11].

$$\mathbf{CNR = (S_1 - S_2)/N_b} \qquad \mathbf{(4)}$$

Where S_1 and S_2 are the signal intensities at two different ROIs and N_b is the background noise

$$\mathbf{CNR = SNR_1 - SNR_2} \qquad \mathbf{(5)}$$

Where SNR_1 and SNR_2 are measured in the signal structures of interest.

Noise removal

The separation of the acquisition and display components of the imaging system in the digital era has enabled noise to be removed from processed images. A digital radiographic image is a numeric representation of pixels based on spatial attenuation of the X-ray beam. Variation in the intensity of these pixels depends on the number and energy of photons absorbed by the detector. The photon fluctuations manifesting as noise can be manipulated to improve image quality. Such fluctuations can be reduced through post-processing using filters [10, 16].

Examples of filters include mean, median, and adaptive (Wiener) filters. Mean filters remove noise by decreasing the extent of intensity variation between neighboring pixels through replacing the affected pixel value with the average of the adjacent pixels. Median filters work by replacing the fluctuating pixel with the median pixel value in the image[17]. Images degraded by blurring and additive noise can be improved with a Wiener filter. This filter works by reducing the mean square error between the fluctuating pixels in the image[10, 16]. Such filters reduce noise levels and improve the diagnostic quality of the images[10, 16]. However, mean filters may reduce the spatial details of the images. Figure 3 shows chest radiographs demonstrating noise removal using filters. In the figure below, A is an image with added noise (σ = 15), which is then filtered by a 4.0 pixel radius using a mean (B) and median filter (C).

Conclusion

Noise produces fluctuations in the optical density of a radiographic image and negatively impacts upon the visibility of image features and through a reduction in image contrast and resolution. Although noise can arise from multiple sources along the imaging chain, the main determinant of noise is number of absorbed or measured by the detector.

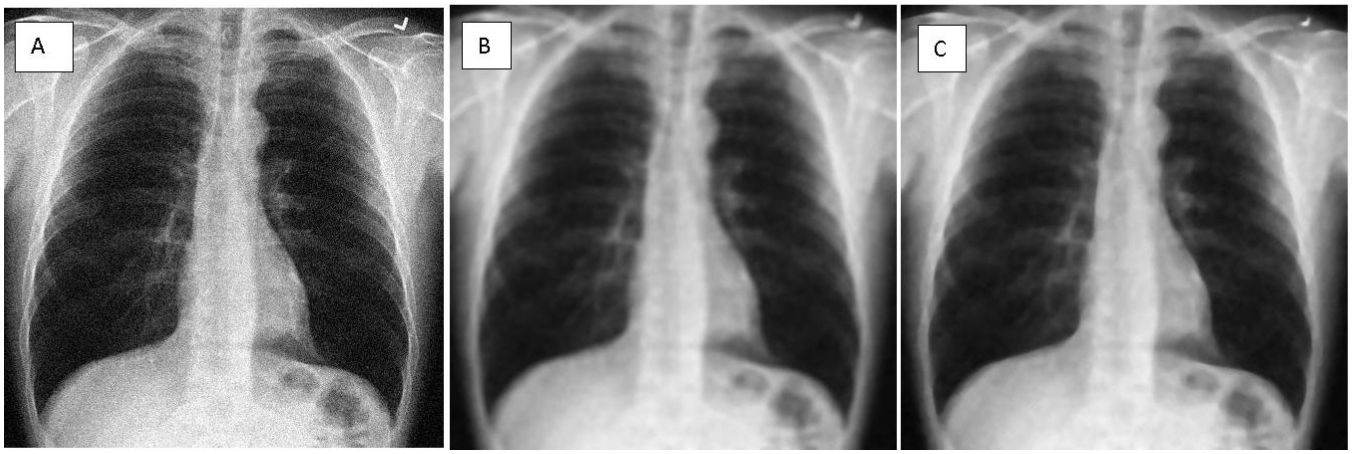

Figure 3: Effect of filters on image features. A: image corrupted by noise (SD =15); B: Image A filtered using a mean filter; C: Image A filtered using a median filter. Note the slight loss of spatial frequency details in B

Signal-to-noise ratio (SNR) or normalized noise power spectrum (NNPS) is a better measure of the impact of noise on the visibility of image features. Finally, the noise in a “For presentation” radiographic image can be reduced using filters.

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How to cite: Egbe NO* and Ekpo EU. Understanding Radiographic Image Noise Measurement and Removal. J Assoc Rad Niger, 2017; 31 (1): 1 – 7