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# Image Noise in Radiography and Tomography: Causes, Effects and Reduction Techniques

EN Manson[1]*, V Atuwo Ampoh[2], E Fiagbedzi[1,2], J H Amuasi[1], J J Flether[3] and C Schandorf[1]

[1]*Department of Medical Physics, University of Ghana, Ghana*

[2]*Oncology Department, Komfo Anokye Teaching Hospital, Kumasi, Ghana*

[3]*Department of Applied Physics, University for Development Studies, Ghana*

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***Corresponding author:** Manson EN, Department of Medical Physics, School of Nuclear and Allied Sciences, University of Ghana, Accra

**Abstract**

The presence of noise in images produced by medical imaging equipment is common and unavoidable. Image noise can obscure and stimulate pathology, even sometimes to the extent of making them diagnostically unusable. To minimize noise in medical images, it is essential to comprehend the sources of noise and how they occur. In this paper, we have reviewed different sources of noise that are present in images produced in radiography and tomography imaging techniques, the causes, effects and the various ways that are employed in their reduction. In order to completely eliminate noise in radiological imaging systems, we recommend that detectors that are free from noise should be designed and incorporated into future imaging systems.

**Keywords:** Image Noise; Tomography; Radiography; Reconstruction; Spatial resolution

## Introduction

The modern application of x-rays diagnosis in conventional radiography and computed tomography (CT) imaging systems can be historically traced to the discovery of x-rays by a German Professor, Wilhelm Conrad Roentgen in November 1895. Roentgen produced a ray emitted from an evacuated glass envelope (tube) with positive and negative electrodes encapsulated in it. When a high voltage was applied to the tube, the tube produced a fluorescent glow capable of passing through a heavy paper covering and exciting phosphorescent materials in the room. This invisible ray, when passed through solid matter and in combination with a photographic plate produces a picture of bones and interior body parts [1]. The fundamental principle for x-ray image formation has basically remained the same since the discovery of x-rays by Roentgen [2]. When x-rays passes through an object of a particular density, part of the x-rays are absorbed whiles part passes through the object and hit a photographic plate to give an image. The quality of the image depends on the amount of x-rays that hits on the plate (detector).

In radiography, when x-rays impinge on a surface such as image receptor, there is no force that causes them to be uniformly distributed over the surface. Due to this uneven distribution, one area of the receptor surface might receive more photons than the other, even when both are exposed to the same average intensity. Within every small area of the image receptor, the amount of noise is primarily determined by the variation in photon concentration from one point to another point. There is an amount of noise produced in all imaging procedures that uses photons because of the random manner in which photons are distributed [3]. However, in computed tomography, image noise can be determined by comparing the level of desired signal (photons) to the level of background noise. This is often referred to as signal to noise ratio (SNR). When the SNR is high, the amount of noise present in an image is said to be less [4]. Image noise can be calculated statistically from the standard deviation of CT number or pixel intensity values in a physical uniform region. As the standard deviation for the pixel values decreases, image noise also decreases [5-6]. There are many different types of noise that are present in the images of medical imaging devices that uses photons. In this review paper, we have characterized the different sources of noise, causes, effects and reduction techniques in radiography and tomography imaging systems.

## Materials and Methods

### Image noise in radiography

Radiographic noise emerges from two main diagnostic imaging techniques. These are conventional x-ray and digital radiography techniques. There are several different sources of noise that are produced by these imaging techniques. In conventional x-ray techniques, there are two main sources of noise. The primary source of these noise is the secondary radiation which is produced as a result of scattered radiation from the x-ray machine and scattered radiation by an object which reach the film. When the useful x-ray beam is intercepted by any object, a secondary scattered radiation is produced. During any x-ray examination, the source of scattered secondary radiation is the patient as shown in Figure 1. The manner in which the film is processed and handled is another way of introducing noise into the final image. This leads to film retake and over exposure of patients to unnecessary radiation. The use of specially designed grid plates made of lead have proven to reduce the scattered secondary x-ray radiation and produce radiographs within acceptable noise level [7]. In a situation where the film is under processed, the sensitivity and contrast is reduced below specific values.

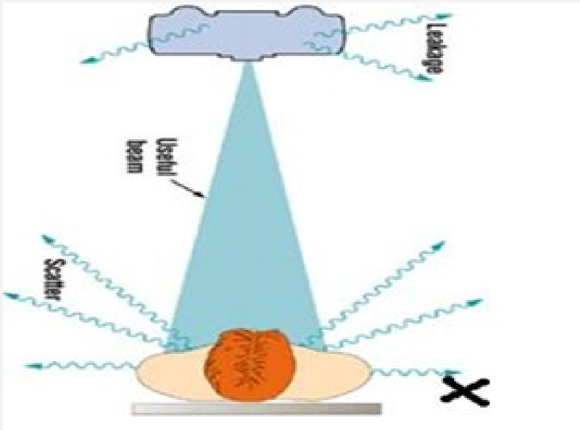


**Figure 1:** Secondary scattered radiation produced through radiation leakage and interaction of radiation with patient.

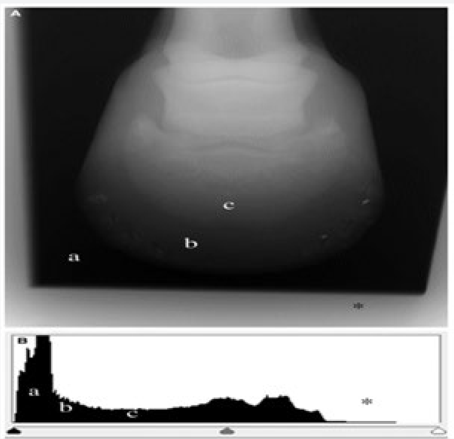


**Figure 2A-2B:** Fig. 2A is radiography with regions a, b, and c within the collimator (anatomy) and region * outside the collimator. Fig. 2B is the corresponding histogram showing the frequency of occurrence on the y-axis and optical density on the x-axis.

Alternatively, when the film is over processed, the sensitivity is increased which increases the contrast up to a point and then decrease. This increases the base plus fog density and thereby contributing to a decrease in contrast [8]. In Figure 2 above, regions a, b and c represent the level of contrast within the radiograph with "a" indicating region of low contrast, "b" indicating region of medium contrast and "c" indicating a region of high contrast. Within the radiograph, areas with high contrast can be suppressed whiles areas with low contrast can be enhanced by the application of a filtering kennel. The application of small kennel size may result in enhancement of only small structures and the application of large kennel size may also result in dynamic range compression with overall impression of increase detail. Also, a medium kennel may also lead to only edge enhancement of the radiograph. In dealing with radiographs of this nature, it is recommended to use multiscale processing. Multiscale processing has the ability to simultaneously enhance relative low contrast objects and suppresses high contrast objects within the entire radiograph. This compresses the dynamic range of the image with high precision [9]. Modern radiography has embraced digital radiography over conventional x-ray radiography due to its advantages which include lower



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diagnostic dose, no chemical development and fixation, image processing and enhancement capability and image transfer. The sensors used in digital radiography systems usually produces large amount of noise in their images. As a result, different digital enhancement algorithms such as noise reduction, sharpening, smoothening, and edge enhancement are used to improve image quality of digital radiography systems [10]. In digital radiography, the different sources of noise that exist originates from most of the elements of the system. These include CCD camera, imaging screen, X-ray source, inspected object, controller circuits and e.t.c. The quality of images depends heavily on these elements. In order to reduce the noise level, different techniques that have been employed in improving the imaging elements and image processing are; the use of collimator, shielding CCD camera from X-ray radiation and summing of the frames. These are accepted techniques that are usually used to reduce random noise and they have been proven to be effective [11].

The common types of noise that are present in x-ray images (Figure 3A & 3B) are Poisson noise, salt and pepper noise, and speckle noise. The salt and pepper is seen in the image as white and black pixels respectively. Poison noise is as a result of uneven distribution of x-rays over the receptor surface [12]. Speckle noise on the other hand occurs as a granular appearance in an image which is produced as a result of random fluctuations in the return signal from an object which is not found to be bigger than a single image processing element. Within a specific area, speckle noise is able to increase the mean grey level. Their appearance is visible in coherent imaging systems such as laser, radar and acoustics [13-14]. Due to the process involved in the acquisition of digital images, some individual pixels in the radiograph vary abruptly in the intensity from neighboring pixels. These pixels contain random noise. Low pass (smoothing) filters are applied to the images to remove the noise in them. These filters which are applied in either spatial or frequency domain have the ability to reduce contrast among neighboring pixels and thereby reducing the amount of noise in the image [7].

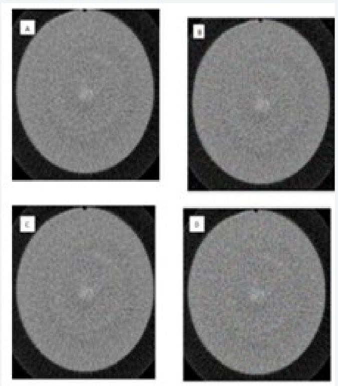

**Figure 3A-3D:** (A) Original Catphan image CTP 712, (B) Catphan CTP 712 image of salt and pepper noise, (C) Catphan CTP 712 image of Poisson noise, (D) Catphan CTP 712 image of speckle noise of variance of 0.02.

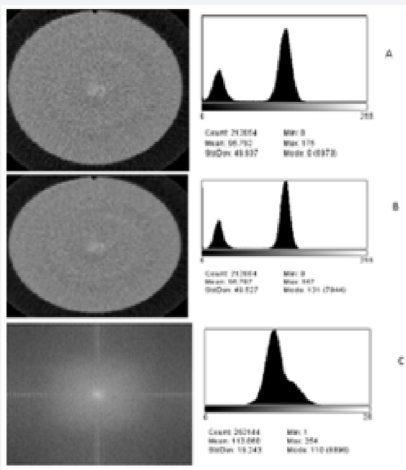

**Figure 4A - 4C:** Images of spatial and frequency domain and their obtained histogram of module CTP712 of Catphan700 Phantom.



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Figure 4A-4C above shows spatial and frequency domain images and their obtained histogram of Catphan700 phantom. Figure 4A show the original image and histogram with a calculated noise level of standard deviation as high as 49.937. The application of a low pass median filter in the spatial medium of radius 2.0 pixels reduces the noise level slightly by 0.824% to 49.527 as shown in Figure 4B. However, when the low pass filter is applied to the original image in the frequency domain of the same radius (Figure 4C), the noise level is reduced sharply by 88.74% from 49.937 to 19.243. There are several different types of filters that can be applied in noise reduction in digital radiography. These include median filter, FIR filter, Gaussian filter, mode filter, convolver, mean, unsharp mask and others. The type of filter to apply in noise reduction is based on the physical appearance upon the application [7]. Also, the choice of filter for reducing noise in medical images depends on the type of noise and type of filtering technique. Among all these linear filters, the Gaussian filter is the most common as it plays an important role in both theory and applications. However, Gaussian denoising filter is known to over smooth images resulting in loss of significant detail, most importantly edge sharpening [12].

## Image noise in tomography

In tomography, the major source of image noise is from the quantum noise properties of x-ray photons and the electronic noise of the detector system. The quantum noise is random as it relates to the number of photons detected whiles the electronic noise originates from the x-ray detector system. Many sources of noise that arise during CT measurement arises from changes in scanning procedure known as technical noise and changes in patient performance also known as biological noise. To minimize technical noise, it is recommended to use a multi-detector array scanner in clinical examinations. On the other hand, the use of low-dose volumetric scanning protocol can reduce biological noise. Reconstructed images should be done using a soft filter defined by the CT scanner [8,15].

In order measure the level of noise, one needs to first define a region of interest (ROI) within the image to obtain pixel intensity values. Statistical analysis of the pixel values produces a bell-shape distribution curve. The amount of spread from the curve can be used to estimate the standard deviation, which represent the level of noise in the image. This is the simplest and surest way of quantifying the amount of noise in CT imaging systems. One way of reducing the level of noise is by measuring the attenuation coefficient values with precision. This can be achieved by increasing the number of photons absorbed in each voxel during the image process. The more the photons in the voxel, the lesser the CT number error in the image as noise and the better the image quality. The amount of noise can also be reduced by varying the size of the voxel. This is because, large voxel size has the ability to absorb the photons than smaller voxel size which will decrease the amount of noise in an image. Alternatively, increasing the total number of photons imparted on a patient is another way of reducing noise [16]. Noise in a tomography image can be reduce through reconstruction. The reconstruction process uses two main methods. These include analytical method (Filtered Back Projection-FBP) and iterative reconstruction method [17].

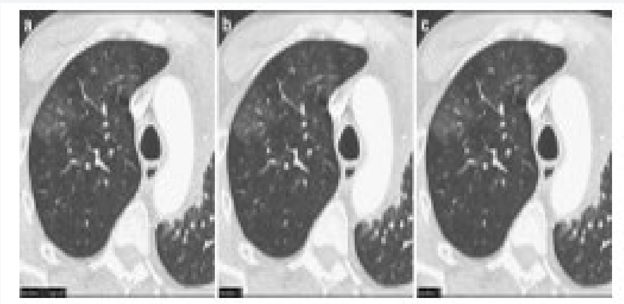

**Figure 5A - 5C:** (a) Reconstructed image of the lung using FBP, (b) Iterative reconstructed image of the lung with 3 iterations, (c) Iterative reconstructed image of the lung with 5 iterations.

The FBP is the standard and regular approach used today in noise reduction. Iterative reconstruction uses a loop correction to calculate a new projection that represents exactly the reconstructed image obtained from the measured projections by ray-tracing in the reconstructed image. A deviation between the measured and calculated projections is determined. This deviation is then used to obtain a new correction projection which is then used to construct the correction image and finally update the initial image. The correction loop continues until the deviation from the measured and calculated projection is found to be lesser than the predefined limit. Whenever the image is updated, the spatial resolution of the image increases and ultimately leads to noise reduction. Figure 5A-5C above shows reconstructed images of the lungs from CT angiography examination of a 55-year-old man. Reconstruction using iterative method shows a reduction in noise level compared to FBP method. The noise in Figure 5A & 5B shows a significant noise reduction of 34.3% and 15.2% respectively when compared with FBP [18]. In x-ray tomography imaging, the projections are formed through the measurement of attenuated radiations


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that traverse a specimen at different angles. Original images are reconstructed through the projections collected by the medical imaging equipment. Reconstructing an image from a projection data can be done either through parallel-beam or fan-beam geometry. In these geometry, the angle at which the projections are made have an effect on the amount of noise produced in the reconstructed image. The use of smaller angles in projection may lead to an increase in noise in the image and ultimately produce significant artifacts in the image. This can be resolved by the use of larger number of angles. Alternatively, the noise in the reconstructed image is also affected by the angle resolution setting. This is because, the projected beam data performs the reconstruction of an image with a specific angle resolution.

The image in Figure 6A is blurred reconstructed image which contains considerable noise as a result of the use large resolution angle (40) when compared to the original image in 6B. However, the use of a smaller angle of resolution setting (10) produces a much clearer image with less noise as shown in Figure 6C. CT systems have an inbuilt reconstruction technique that uses a mathematical process to filter images and to reduce noise in them. The systems uses different filters that have different image smoothing characteristics towards noise reduction. For example, the use of the edge enhancements filter in noise reduction may result in an increase in the visibility of noise [16]. The type of filter used in the reconstruction process have a direct effect on the image quality. A smoother kennel (filter) produces images of lower noise but with reduce spatial resolution.

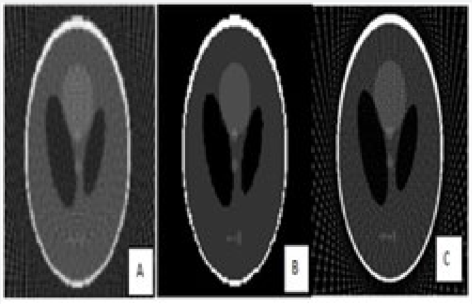


**Figure 6A - 6B:** (A) Reconstructed image of a Head Phantom at 40 by FBP, (B) Original image of the Head Phantom, (C) Reconstructed image of a Head Phantom at 10 by FBP.

Conversely, a sharper filter will result in more noise but with higher spatial resolution. The type of filter should also be based on specific clinical applications. For instance, the use of smooth filters in brain or liver examinations are preferred to sharper filters due to the ability of better spatial resolution. In CT, the selection of slice thickness for image reconstruction is very critical as it plays a very important role in image quality. During reconstruction process, the choice of slice thickness directly influences noise and spatial resolution of an image [17]. For fine detail and three-dimensional (3D) reconstruction, it is recommended to use a slice thickness of 1.25mm or less. The use of higher slice thickness may produce additional noise and result in loss of detail that may be relevant in forensic investigation [19]. On the contrary, reconstruction using a thinner slice thickness (< 1.2mm) introduces dimpling artefacts in an image with increased noise. It is therefore important for the CT user to minimize radiation dose and optimize image quality by selecting the appropriate slice thickness based on the type of examination.

## Conclusion

Radiological noise comes from different sources and can greatly affect the quality of images produced by radiographic and tomography imaging techniques. Manufacturers of modern imaging devices have integrated a software into their scanners to enable reconstruction of images towards noise reduction and improve image quality. However, reconstruction of images sometimes leads to an increase in dose but with reduction of noise and improve image quality. Ideally, reconstruction of image should be performed to reduce noise, minimize dose and improve image quality. Since noise is non-avoidable in radiological imaging, it is recommended that, radiographers, radiologist and medical physicist should be able to quantify the amount of noise in a clinical image, apply the appropriate reduction technique to reduce noise to the minimum, whiles reducing radiation dose to the minimum level as possible and improve image quality. Noise free detector features is also highly recommended and should be incorporated in future designs of radiological imaging systems.

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