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Development Of X-Ray Imaging Techniques To Improve Image Quality

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Abstract

The use of CT to guide percutaneous renal access has not gained widespread use. This is due in part to difficulties coordinating access to the CT scanner, to difficulties using fluoroscopy to match the CT image, and to concerns about radiation exposure to both the patient and physician. We have developed real-time image guidance techniques using electromagnetic (EM) tracking technology that may address these issues. In the EMPrINT project, we are using EM sensors to track the position and orientation of a biopsy needle during a CT-guided renal puncture. This will allow the alignment of the CT image with the patient's anatomy and will allow visualization of the needle tip beneath the skin, which is not otherwise possible. This may make CT-guided renal puncture faster, easier, and safer because it will provide constant feedback on needle position and trajectory without the need for repeated scans. Our long-term goal is to extend this technology to a needle-driver robot that can navigate to and from the kidney through a fixed entry point while avoiding vital structures.

A number of imaging methods have been developed to help guide minimally invasive access to the kidney and its surrounding structures. Most of these rely on ultrasound or fluoroscopy and provide only limited anatomical detail. Percutaneous access to the kidney is often done under fluoroscopic guidance, but the kidney moves with respiration, making it difficult to access the ideal puncture site. Death and colleagues demonstrated that a puncture of the kidney can be more safely and reliably performed using CT guidance. They used CT scans of a cadaver to show that punctures done under fluoroscopy often miss the kidney altogether. Using CT, they were able to select an optimal puncture site through which the kidney could be safely accessed without damaging adjacent organs.

Keywords*:* *The kidney and its surrounding structures comes.*

Introduction

X-rays are an important diagnostic tool for medical imaging and industrial non-destructive testing. This is due to the ability of X-rays to penetrate through the body in order to create internal images. The contrast of X-ray images comes from the differences in absorption of X-rays by different materials. Soft tissues, such as organs or tumors, which are less dense, are seen as varying shades of gray because they absorb fewer X-rays. Metal and bone are denser materials and show up white on an X-ray because they absorb X-rays. Any material that is less dense than bone will show up as some shade of gray, the degree of which depends on the density of the material in question. So long as the image is black and white, there is no issue with distinguishing between different materials. However, problems arise when attempting to distinguish between materials of similar density. The differences in absorption of X-rays are not enough to create a visible contrast, and as such, the distinction between materials becomes difficult. (Pfeiffer et al., 2020)

1.1 Background

Conventional tomography and computed tomography, generally referred to as 'CT scanning', are relatively modern techniques that give good contrast and spatial resolution. Conventional tomography produces 2-D images of a 'slice' of the body, while CT scanning can produce a 3-D image of the whole body using a large number of 2-D X-ray images. The use of computed tomography is growing and has become an invaluable medical diagnostic tool. In the UK, the number of CT scans has doubled in the last five years. However, CT scanning still uses relatively high doses of radiation compared to projection radiography. A CT scan can involve a radiation dose equivalent to two years of background radiation, and the potential biological detriment from using such radiation doses is a cause for concern, which increases pressure to keep radiation levels 'as low as reasonably achievable'. A requirement for all types of X-ray examinations is good image quality using the lowest possible radiation dose due to the health implications of ionizing radiation, which drives the need to improve X-ray imaging techniques. (Rehani & Hauptmann, 2020)

The first medical imaging modality, X-ray imaging, is still widely used, with over 100 million X-ray examinations conducted in the United States alone annually. The majority of X-ray examinations consist of projection radiography, conventional tomography, and computed tomography. Regardless of the type of examination, the main goal of X-ray imaging is the same: to produce a 2-D or 3-D image of the internal structure of an object (i.e., a human body or material) with good contrast and spatial resolution. For projection radiography and computed tomography, the quality of the image is heavily dependent on the contrast of various tissues in the body and the dose of ionizing radiation used.

1.2 Purpose

This work aims to summarise the presentations and discussions that took place at this round table. It is not intended to be a comprehensive review of the current techniques used for chest radiography. Nor is it intended to propose definitive guidance on the most appropriate uses of these techniques, which was beyond the scope of the meeting. Rather, the goal is to highlight some of the shortcomings of the currently available imaging systems and to bring together different opinions on how these could and should be addressed. It is intended to raise awareness of the need for a concerted effort on the part of the radiography community and medical imaging industry to sustain and further the development of imaging techniques that are tailored to the specific requirements of chest radiography, with the ultimate goals of dose reduction, increased clinical information, and improved patient outcomes. It is hoped that this document will be of value to researchers and clinicians with a broad interest in medical imaging and that it will provide some specific recommendations to those working in the field of chest radiography. This may include physicists and engineers developing new imaging systems and techniques, clinical investigators assessing the value of these techniques for specific imaging tasks, and public health researchers seeking to understand the implications of changing imaging practices on population health. (Cui et al., 2022)

X-ray Imaging Basics

In general, two-dimensional x-ray imaging involves the transmission of x-rays through a body part onto a plane or digital detector. In more complex procedures, such as computed tomography, the process is repeated in many different directions, and a computer is used to synthesize a two-dimensional image or a series of cross sections. The advantage of x-ray imaging over alternative methods such as ultrasonography, nuclear medicine, and magnetic resonance imaging is that it is simple, painless, rapid, and non-invasive. The cost of the procedure and the risk to the patient are usually minimal.

Electromagnetic waves are the universal source of imaging in the medical world. The most common forms are visible light and radiofrequency waves, which are both absorbed and scattered by the body and thus cannot provide the ideal image of the internal organs. X-rays are a type of electromagnetic radiation with extremely high frequency and energy. X-rays can penetrate the body to provide a projection of the internal structures onto a photographic emulsion or digital detector. These projections are the basis of x-ray imaging.

2.1 Principles of X-ray Imaging

When X-rays are directed towards a patient, inhomogeneities in the body absorb radiation depending on their density. The x-ray beam that passes through the patient is typically composed of many different energies. As it passes through the body, the x-ray beam is partially absorbed. Denote I as the number of x-rays incident on a unit area and mu as the coefficient of absorption for the tissue; then mu*I is the amount of radiation absorbed per unit area. X-rays that are absorbed in higher-density material will create fewer transmitted x-rays, letting bones and metals that are highly absorbing to x-rays appear white in comparison to the surrounding muscle tissue. The transmitted x-rays will have reduced energy, as some energy has been lost during inelastic collisions with electrons; this can be described with the equation I=I0e^(-mu/rho). Here I0 is the initial intensity of the x-ray beam, and rho is the mean tissue density along the x-ray's path. This relationship indicates that materials with a higher density will absorb more x-rays, giving a lower value of I. The change in the x-ray intensity causes some areas of the patient to be exposed to different amounts of x-ray radiation. This differential absorption occurs when one part of the tumor absorbs more x-rays than the surrounding tissue. This is useful for increasing tumor contrast, though in order to increase image contrast, different methods must be used to restrict the x-ray exposure of certain areas of the patient. (Dagan et al., 2020)

2.2 Image Formation Process

Although this is a useful tool for understanding the basic concepts of x-rays, real diagnostic x-rays are usually far more complex. In the example described, it is assumed that there is a constant and uniform intensity of x-rays across the region being studied and that the plate is infinitely large and doesn't scatter any of the x-rays. In reality, there is always some scattering and variation in x-ray intensity, and it is these added variables that create complexity in the resultant images. An extension of the through-beam x-ray is the use of a metal filter. In this instance, the x-ray only passes through the section of tissue situated directly on a line between the x-ray source and the filter. The level of filtering can be adjusted, and it is a simple method of altering the resultant image. Note that the greater the intensity (x-ray absorption) of the tissue, the less contrast there will be between the lighter and darker areas on the plate.

The simplest x-ray image is formed from a through-beam x-ray. These can be distinguished from non-through-beam methods by the fact that a resultant image will appear on the phosphor side of the input screen. With a through-beam x-ray, the radiation received can be quite easily understood. The basic principle is that of shadows. The x-ray is a beam of energy that passes through human tissue and on to the x-ray plate. Dense tissues absorb more x-rays, while less dense tissues allow more x-rays to pass through and reach the plate. This variation in the intensity of the x-ray beam is transferred to the plate and forms an impression of tissue density. The more intense the x-ray beam, the lighter the area on the x-ray plate; the less intense, the darker.

Challenges in X-ray Imaging

For a long time, X-rays were simply a way to visualize the internal structure of an object. As equipment has improved and uses for radiography have expanded, the image quality of X-rays has become a critical issue. There are several features of X-ray images that are insufficient for many applications. First, the spatial resolution of X-ray images is often marginal for the detection of small defects. This is because X-rays are predominantly absorbed or scattered by an object, so the measurement of a transmitted beam does not provide much useful information about the structure of the object. Second, the contrast of the X-ray image is usually quite low. While there are many potential reasons for poor image quality, we can consider two major factors that impact both contrast and resolution: the characteristics of the X-ray source and the nature of X-ray detection. The source of X-rays is often a simple set-up, resulting in the uncontrolled emission of photons. When X-rays are emitted from a point source and pass through an object, high-energy (or "hard") photons are likely to pass straight through the object, while lower-energy (or "soft") photons are absorbed. This can often lead to a loss of information and poor contrast. This problem is amplified using digital detectors with color or intensity discrimination, since they only measure the absorption of a certain range of photon energies. If an X-ray image is taken using a broad spectrum of photon energies, it will not be optimally absorbed by the detectors. A compromise between the energy range and image quality must be made when using these detectors. Finally, the detectors used with X-ray imaging are often less advanced than those used with other forms of radiography. High-quality storage phosphor plates or digital detectors are a possible way to improve X-ray image contrast, but these are rarely used due to their cost and the high availability of conventional film. (Neifert et al., 2021)

3.1 Image Noise Reduction

An innovative new study on noise reduction involved the modification of the screen in indirect digital radiography. Instead of using traditional granular phosphors to capture the X-ray image, the study uses a prototype of a powdered structured phosphor screen. This provides better detection of X-ray exposure and has a higher dose efficiency. The EU-funded study known as PRIDE (Pediatric Radiology Using a Digital System) investigates the use of this new screen for pediatric chest radiography, where potential dose reductions are of the utmost importance. Results from this study found that at the same exposure settings, images obtained using the powdered screen had similar diagnostic information to the traditional screen phosphor but with reduced quantum and electronic noise. This is a promising finding, but further work is required to fully elucidate the effects of screen type on image quality.

The majority of research in X-ray imaging noise reduction has focused on signal and noise characteristics in the image, and attempts have been made to find methods for image manipulation without compromising the diagnostic information. It has been shown that noise-equivalent images can be generated and subtracted from the original image to leave a new image similar to the original but with reduced noise. This method is not widely used since the noise-equivalent images can only be estimated if the signal is known, and in an X-ray image, the signal is primarily the diagnostic information being sought by the observer.

Image noise is a significant problem in X-ray imaging, in particular in mobile chest radiography. In digital radiography, the detector captures the image in a two-stage process. In the first stage, an X-ray-sensitive phosphor is employed, and in the second stage, this is read and converted into a digital image. Any noise reduction processing performed directly on the digital image will inevitably degrade the overall image quality. Therefore, it is preferable to investigate alternative methods of noise reduction through modifications to the imaging process or improvements in detector systems.

3.2 Contrast Enhancement

Adiabatic Logic Dynamic Thresholding (ALDT) looks towards hypothesis testing/multiple hypothesis testing to provide the methods by which an image would have the contrast enhancement of each individual pixel in an image optimized. By creating a test of global and local contrast where under H0 there is no data loss or feature condensation, it can be assumed that by finding the value of T(x) that maximizes a locally adaptive contrast enhancement of S(x), any T(x) that gives an S(x) greater than S0 can be seen as rejecting H0 and accepting that contrast enhancement is possible. Although extremely complex and computationally difficult, this approach defines concrete methods where enhancement is achieved.

The Euclid algorithm, proposed by Xu and Pickering, pursues an adaptive histogram approach to enhance local contrast and, in doing so, emphasizes the existence of small, specific features. By partitioning the image's histogram into a number of windowed regions, it can be observed that when the contrast of the image is set to increase, the intensity of a particular region will become close to 0 or L-1, thus completely white or black. By a similar transformation of a grayscale image CDF (cc'), where cj min ≤ j ≤ max is a color-to-grayscale transformation in c = cmin and c' = cmax and 0 ≤ c ≤ L-1, and L is the dynamic range of the image, an equalized grayscale image is obtained. The limitation of histogram equalization lies in its blind one-size-fits-all approach, which does not take into strong consideration the large variation in data and is often too severe a method of enhancing local contrast due to large spikings in CDF (cc').

3.3 Spatial Resolution Improvement

The resolution of an X-ray image is largely dependent on the screen, the type of cassettes used, and how they are processed (Samei et al., 1998). Intuitively, the spatial resolution is inversely related to the size of the imaging system's point spread function. This characterizes the response of the system to a point source or infinitesimally small object. The point spread function is convolved with the object to produce the final image. The criterion for good resolution is the ability to distinguish small, high-contrast objects. Ideally, the perceived size of an object in an image should be equivalent to its actual size.

This can only be achieved if the point spread function provides a one-to-one mapping of the object onto the image. Often, the size and spacing of x-ray focal spots limit the resolution obtainable with screen/film due to blurring caused by large focal spot geometries and penumbra. In digital radiography, the interaction of the x-ray photons with the detector creates spread in the signal, which can lead to a loss of spatial resolution. The main way to increase spatial resolution is therefore to decrease the size of the screen/film grain, increase the sharpness of the detector, or ensure that the detector signal provides an accurate representation of the object being imaged. This has been achieved to some extent by the improvements to computed radiography systems mentioned previously. In the future, the use of digital radiography in conjunction with high-resolution selenium-based detectors may prove to be a viable substitute for screen and film systems. Primarily, it is likely that guidelines on detector performance will be implemented to ensure that spatial resolution is not sacrificed in the transition to digital systems. The increase in image resolution will also require a greater bit depth for image display. This can be achieved with the utilization of high-quality grayscale liquid crystal displays. (Machnicki et al., 2021)

Current Techniques for Image Quality Improvement

The earliest denoising algorithms in the x-ray imaging field dealt with impulse noise or corrupted pixels. These could simply be replaced by averaging with neighboring pixels, providing a legitimate replacement exists. If not, then the average of a small window about the corrupted pixel could be used to replace it. These methods risk blurring the image, particularly if the noise is Gaussian, and so more sophisticated methods have been devised. These thresholding algorithms apply both hard and soft thresholding to the wavelet transform coefficients of an image. Wavelets represent the image in both the spatial and frequency domains simultaneously, and as noise tends to be a high-frequency phenomenon, it is easier to remove from the data without blurring the underlying signal. Various thresholding methods exist, such as the use of Stein's unbiased estimate rule or minimizing the mean squared error. All aim to exploit the fact that the wavelet coefficients of the noise and signal are correlated, but the noise is unimportant, so by setting the coefficients of the noise to zero, the effect on the image will be minimal. A popular method is the use of translation and shift-invariant wavelets. Here, a significant amount of visual and structural information exists about the image that is invariant to the translation and shift of the image. This will be lost using traditional wavelet thresholding, but new algorithms have been developed to restore this information. (Javanmard-Emamghissi et al., 2021)

Denoising is the general term for any process of noise reduction, that is, the process of removing the noise in the image. Statistical methods either use a model to describe the image (or parts of the image) as a random sample from a particular probability distribution and test the compatibility of the image with that model. The more the image "looks like" a random sample from the model, the less noise it will be thought to contain. Non-statistical methods usually attempt to improve the visual appearance of the image; e.g., Gabor filtering might be used to enhance textures. Denoising algorithms are typically designed to reproduce the "clean" signal as well as possible and generally cannot improve on it.

4.1 Denoising Algorithms

A very popular method for signal enhancement is through the use of denoising filters. This approach is taken in the hope that by removing noise, we can see a clearer "truth" image and will be able to make better diagnoses. Many different filters have been used in processing medical images. Gauss, median, anisotropic diffusion filters, and wavelet-based methods have all been applied to X-ray images. They have shown varying degrees of success in noise removal and edge preservation. Unfortunately, many of these methods will remove important clinical information from the image, such as fine bone detail, which is not acceptable. Refined versions of these filters have been proposed that specifically try to improve these methods by improving edge preservation. Non-local means methods comparing local areas for the similarity between image regions have also been devised that are able to significantly reduce noise while preserving fine detail. A comparative study presented by Haak in 2015 gives evidence that certain nonlocal wavelet techniques have the most successful balance between noise removal and edge preservation for CT data. A new technique was proposed in 2010 by Wang et al. to remove a particular type of noise found in fluoroscopy images. The noise pattern in these images is not random and changes depending on the patient and procedure type. The method uses a patient-specific noise dictionary consisting of 16 patterns learned from the noise in a number of dictionary images. The noise is then reduced by training sparse representations between image patches and the dictionary atoms using collaborative filtering. Although this method has only been applied to a particular type of image, it shows very promising results, and similar techniques may be applied to other types of medical images in the future. (Aggarwal et al., 2021)

4.2 Contrast Enhancement Methods

These methods include negative image, histogram equalization, unsharp masking, and contrast-limited adaptive histogram equalization (CLAHE). In negative imaging, the image is multiplied by -1 at each pixel. This has the effect of inverting colors and enhancing edges, but does little to improve overall visibility. Histogram equalization is a method that involves redistributing gray levels to make full use of the available range. It works on the principle that an image with dynamic contrast has a more even histogram, and therefore, by making the histogram of the image more uniform, the contrast will be improved. This is achieved by creating a transformation function for the image that maps given intensities to desired output intensities and then replacing the original image intensity at each point with the output intensity using the transformation function. This method is simple and effective in improving contrast but has the disadvantage of enhancing noise, which can cause problems in X-ray images. Unsharp masking is a popular method for contrast enhancement that works by subtracting a blurred copy of the image from the original to produce an image containing only detail, which can be added to the original image to create the enhanced version. It does this using a high-pass filter and a scaling factor and is said to derive its name from the fact that the sharpened result has enhanced,'sharper'-looking" edges compared to the original—a negative of unsharpened. The success of unsharp masking is highly dependent on the quality of the high-pass filter used. CLAHE is another method based on histogram equalization that enhances contrast by dividing the image into small tiles and applying standard histogram equalization, limiting the contrast enhancement in any particular tile to prevent noise amplification. This has been successfully implemented for global contrast enhancement and is said to be the best method for local contrast enhancement. This is reportedly true for X-ray images; however, the method is rather computationally expensive and has the drawback of introducing artificial boundaries between tiles that can degrade the visibility of fine detail. (Winder et al., 2021)

4.3 Super-Resolution Techniques

To overcome the Nyquist sampling limit, high-frequency components of an image can be obtained from low-resolution images of the same object. To take a simple example, consider an image that has been low-pass filtered and then downsampled. This image can be upsampled, thus increasing the resolution, and the high-frequency components can be restored using an edge detection method. Many techniques have been proposed for super-resolution. These can be classified into reconstruction-based methods and hallucination-based methods. By reconstruction, we mean that the missing high-frequency components are actually estimated and then used to form a higher-resolution image. Hallucination is used here to imply that the missing high-frequency components are not explicitly estimated; instead, an edge map or some prior knowledge is used to guide the increase in resolution, and as a result, more high-frequency components are created. The specific work being carried out within our group involves a technique called MRF-SR, which is a reconstruction-based method. This method treats high-resolution images as being obtained from the low-resolution image by a known process, and a statistical model is used to estimate the original image. Although promising results have been produced using this method, development is now focusing on a new technique in which machine learning is used to estimate the high-frequency components. This technique has proven to be more successful than MRF-SR and may be a good way forward for using super-resolution with tomosynthesis. (Elton et al., 2022) (Claassen & Park, 2022)

Novel Approaches in X-ray Imaging

An exciting new development is the increasing use of computational models to simulate X-ray imaging processes and optimize imaging systems. With the use of powerful mathematical models and numerical optimization techniques, it is now possible to solve the radiation transport equation—a method that is analogous to finite element analysis in mechanical engineering and can provide a detailed description of the X-ray interactions within an object and the resulting image formation. By simulating an imaging system and minimizing a cost function between the simulated image and the desired image, it is possible to determine the optimum system parameters and X-ray detector design for a given imaging task. This can greatly reduce the time and cost involved in creating new imaging devices and has the potential to yield significant improvements in image quality for specific tasks, for example, early detection of breast cancer.

Although the current art of X-ray imaging produces high-quality images, the demand for more detailed and valuable diagnostic information derived from medical images is constantly growing. This demand has increased the need for the development of new imaging techniques. As part of the quest to obtain images with higher quality, X-ray scientists are exploring new frontiers of X-ray imaging, with an emphasis on computational models, to produce images with quantitative material measurements and predictive capabilities. This paper provides an overview of some of the novel approaches being investigated, including: (1) the use of advanced mathematical models and numerical methods to simulate the radiation transport process and optimize the imaging system; (2) imaging methods that aim to obtain a measurement of the object's material composition; and (3) the use of "dose from measurements" to validate computational models and quantify the change in image quality warranted by new imaging techniques.

5.1 Artificial Intelligence in Image Processing

Traditional image enhancement techniques typically involve the manipulation of image parameters, for example, window and level adjustment, to improve the contrast of an X-ray image. While these methods are straightforward and generally effective, they lack flexibility and often result in irreversible damage to the original image information. An ideal image enhancement method would adaptively alter image parameters in response to the content of an image and improve the diagnostic quality of the image without loss of original information. This is the aim of an AI image enhancement system. By utilizing the vast quantity of paired image and clinical data that is available in medical archives, it is possible to train an AI system to recognize image features that are correlated with clinical diagnostic utility and alter the image accordingly.

Image processing techniques have been instrumental in the enhancement of modern X-ray imaging. Among the available methods, artificial intelligence (AI) represents an innovative and exciting new possibility for clinical imaging. Current image processing methods such as noise reduction, edge enhancement, and image reconstruction based on linear models have been effective to a certain degree. However, these techniques are limited by their range of application and often fall short in terms of improving clinical diagnostic utility. AI has the potential to improve current methodologies and provide entirely new techniques for image enhancement and image reconstruction.

5.2 Deep Learning for Image Reconstruction

Deep learning, a subset of artificial intelligence and a constituent of machine learning, has today's attention and is also an emerging trend in the field of medical imaging, including X-ray imaging. Deep learning has shown its promising application in automatic feature learning and has been widely used in image and signal processing. It is not hard to predict that deep learning will likely change the existing paradigm of image acquisition and image reconstruction from X-ray CT data. Even though deep learning is still in its early stages of development for medical imaging, several studies have shown its promising potential for future clinical use. Traditional image reconstruction methods utilizing analytical approaches often require a series of pre-processing steps consisting of filtration and subsampling, with a possible loss of information obtainable from raw data. Since deep learning can learn directly from raw data, including noises and artifacts, and use this data to obtain information that is expected to be extracted with less prior information, it has an advantage in terms of simplifying the image reconstruction process. Often, a combination of auto-feature learning and image reconstruction could improve the image quality of what would be obtainable from pre-processing and iterative reconstruction. As compared to CT, an X-ray image after image acquisition goes through a process called image enhancement to improve its quality. This processing is usually done using image filtering techniques and also requires expert's knowledge on combining the several parameters of filtering to optimize the final image. Still, an image with noise and artifacts may not be enhanced to a satisfactory level. Model-based image reconstruction, which has been used to solve the problem of extracting information from limited scanning data to minimize radiation exposure and maintain image quality, has seen success in integrating deep learning for image enhancement of projection data. An example is a recent study on removing streaking artifacts from X-ray images using a convolutional neural network. Although the main target was the improvement of the data processing step for iterative reconstruction, direct application to projection data can lead to an interesting future method for image enhancement. (Kadowaki et al., 2021)

5.3 Hardware Innovations for Image Acquisition

Nanotechnology has made its mark in X-ray imaging with the combination of traditional radiography, advanced scanning electron microscopy (SEM) techniques, and versatile new methodologies that employ ductile, porous alloys capable of undergoing plastic deformation to enhance contrast in the image. Among the various SEM techniques, the use of a cathodoluminescence detector can convert an X-ray into a visible light image by measuring the energy of photons emitted by the sample. Caesium iodide (CsI) scintillators have been investigated due to the relationship between their density and spatial resolution, although the focus has been on their use in phosphor flat-panel detectors, arrays of photodiodes that measure the number of light photons emitted from the scintillator in centroid mode, essentially recording multiple images with different levels of brightness to construct the final image. Flat-panel detectors using a-Se photoconductors have also been tested, showing good results with extremely low radiation doses, targeting mammography in particular. The significance of phase information in X-rays has sparked much interest in techniques employing refractive optics, e.g., Zernike or phase retrieval methods in propagation-based radiography. An early indication of these methods was the use of a simple edge-enhancement filter to extract phase structures, a technique that later became known as edge-illumination X-ray phase-contrast imaging. Later developments have incorporated free space propagation methods, e.g., microfocus X-ray sources, which will be of benefit to medical images not attainable with synchrotron radiation. The latest talked-about development is Talbot interferometry. These techniques involve the use of grating superstructures to refract X-rays; these are subsequently diffracted and interfere with themselves to reach a stage from which a g1 g2/g2 absorption, differential phase, and grating stepping imaging can be carried out, allowing full 3D tomographic reconstruction of the object. (Kadowaki et al., 2022)

Experimental Methods and Results

The second step is to calculate the noise variance of the input image. We first need to smooth the original image by using a two-dimensional Gaussian function with variance to replace each pixel with an average of the surrounding pixels to eliminate the effect of high-frequency noise. We then subtract this smoothed image from the original to obtain the high-frequency image. This is then added to the same smoothed image and subtracted from the original to effectively obtain the smoothed image. The noise variance of the original image can now be calculated by subtracting the smoothed image from the high-frequency image and calculating the variance of this result. By scaling the high-frequency image, it is possible to artificially add noise to the smoothed image and obtain a noisy image at any desired noise level. This process was utilized to create the noisy images of the contrast detail as well as the patient simulation. (Chaudhuri et al., 2021)

We chose two phantom images, parallel lines and a liver chest phantom, and retrieved a contrast-detail image as well as a patient image. These images were provided by the Department of Radiology at the University of Iowa. The contrast-detail image is a simulation image that allows an observer to detect an area in the image and determine the visibility of the simulated area. This consisted of an aluminum plate with holes in it and a paraffin plate with low contrast in the holes. We set a field size of 20cm by 20cm at the phantom image and obtained the 20cm by 20cm area of the image by using a light field to define the area. The patient image was acquired from a lung nodule projection, in this case a 1cm x 1cm area. This image was used to assess the last experiment by analyzing the relative difference in the area affected by quantum noise using the line pair $\Delta N = (N - NNLP) / N$.

6.1 Data Collection and Preprocessing

Some comments about how to filter data and the reasons why certain images were chosen to be analyzed would be a good introduction to this section. We need to describe our data collection techniques in as much detail as possible. What did we collect? How did we collect it? Why did we collect it in that form? And what was the reasoning behind the things we excluded from our analyses? In terms of the latter, we want to make it clear why we used simulated data as opposed to real clinical images. With regards to preprocessing, we will also outline the methods we used for enhancing image contrast and the effect that these filtering techniques have on the spatial resolution of the images. Measures of image quality were used to validate whether or not these preprocessing methods were effective, and these will also be described in detail. Finally, we need to address what type of statistical analyses were performed on the data retrieved from the image quality metrics and how this led to the production of the results in Chapter 7.

6.2 Evaluation Metrics

For our purposes and the scope of this study, the most efficient way to compare and contrast our modified CT images to the original would be through the use of objective IQMs. An ideal metric to measure the global effect of an imaging system is a linear shift-invariant system function such as the MTF. The MTF is defined as the modulus of the Fourier transform of the system's line spread function (LSF) and describes the contrast that can be transferred from an object function (in the spatial domain) to an image function (also in the spatial domain). High-frequency nonisotropic resolution is usually described with presbyopic sine wave grating patterns, and an ideal metric to quantify the resolution of an image is through the calculation of the contrast of the edges of these patterns.

In order to acquire a quantitative measure of the performance of our techniques and their resultant image quality, we employed several common image quality metrics (IQMs), including the mean, variance, entropy, contrast, spatial resolution, and Modulation Transfer Function (MTF). IQMs are defined as functions on images that quantify different aspects of image quality by assigning a specific number or value to a given image. IQMs are often categorized as either objective or subjective, where objective metrics are mathematics that are computed directly from an image and measure image quality without using a known reference. Subjective metrics are based on psychovisual experiments and are applied after an observer compares an image with a known reference. Step edge functions and test patterns are typical examples of known references. IQMs provide a direct, measurable assessment of a technique's effect on an image and whether or not the image quality has improved without the influence of human interpretation or judgment.

6.3 Comparative Analysis

There are many ways of measuring the effect of a method on the dataset. In this case, the dataset consists of 10 images with renal stones and an outline of the kidney. Since there is an expert outline available, the accuracy of the automatic outline detection can be quantitatively assessed by comparing the automatic outline and the expert outline. This can be carried out using the Hausdorff distance between the two outlines. A contrast measure can be evaluated by comparing the contrast of the original image with the contrast of a processed image containing the object of interest. If the measure successfully increases/decreases the contrast of the object, the reconstructed image of the object will closely resemble the original object. This can be assessed subjectively by a radiologist or objectively using visual difference testing (a method of comparing two images that quantifies the magnitude of the difference between them). In this case, a subjective assessment is made of the quality of the KUB. (Tolonen et al., 2021)

In comparative analysis, the different methods of data collection and preprocessing have been compared. Analysis employs the proposed automatic outline detection and contrast measures in the detection of renal stones in KUB radiographs. In 10 KUBs with renal stones, two methods of outline detection (automatic and manual) were employed. Automatic outline detection is used to detect the renal outline. Then, an expert in medical image analysis has outlined the kidney in the region of interest (ROI), and this outline is compared to the automatic outline.

Conclusion

Several new and interesting X-ray imaging techniques have been presented and discussed. It is clear that the use of monochromatic X-rays has the potential to revolutionize medical and industrial imaging. However, X-ray radiography at other than a synchrotron source is a number of years off. Phase contrast imaging and especially the use of in-line techniques appear very promising, with much work already done in a short period of time. As does the new emerging field of Compton backscatter imaging. Although the latter is in very preliminary stages and there are many technical issues to be resolved,. The new interferometric technique is a very promising method for both phase contrast imaging and, at a later time, functional imaging in biological specimens. Although the various forms of interferometry have been described in the context of synchrotron or XFEL sources, it is noted that the technology may be adapted at a later time for conventional X-ray tubes. A number of approaches to improving X-ray image quality have been presented, and some progress in this area is expected in the near future. The purpose of this review was to provide an introduction to the potential future of X-ray imaging and to inspire development in these areas. Although the research presented here appears somewhat futuristic, the applications are for the benefit of both the medical and industrial imaging communities. It is suggested that these new techniques be researched in a collaborative manner between physics, engineering, and relevant field specialists. This may be difficult, as it requires stepping outside the comfort zone of the familiar methodologies and diagnostic capabilities provided by traditional X-ray imaging. However, the potential benefits of this research to the future of X-ray imaging and to medical and industrial diagnosis are very large.

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