Introduction

The last two decades have witnessed significant advances in medical imaging and computerized medical image processing. These advances have led to new two-, three- and multi-dimensional imaging modalities that have become important clinical tools in diagnostic radiology. The clinical significance of radiological imaging modalities in diagnosis and treatment of diseases is overwhelming. While planar X-ray imaging was the only radiological imaging method in the early part of the last century, several modern imaging modalities are in practice today to acquire anatomical, physiological, metabolic and functional information from the human body. The commonly used medical imaging modalities capable of producing multidimensional images for radiological applications are: X-ray Computed Tomography (X-ray CT), Magnetic Resonance Imaging (MRI), Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET) and Ultrasound. It should be noted that these modern imaging methods involve sophisticated instrumentation and equipment using high-speed electronics and computers for data collection, image reconstruction and display. Simple planar radiographic imaging methods such as chest X-rays and mammograms usually provide images on a film that is exposed during imaging through an external radiation source (X-ray) and then developed to show images of body organs. These planar radiographic imaging methods provide high-quality analog images that are shadows or two-dimensional projected images of three-dimensional organs. On the other hand, recent complex medical imaging modalities such X-ray CT, MRI, SPECT, PET and Ultrasound depend heavily on computer technology for creation and display of digital images. Using the computer, multidimensional digital images of physiological structures can be processed and manipulated to visualize hidden characteristic diagnostic features that are difficult or impossible to see with planar imaging methods. Further, these
features of interest can be quantified and analyzed using sophisticated computer programs and models to understand their behavior to help with a diagnosis or to evaluate treatment protocols. Nevertheless, the clinical significance of simple planar imaging methods such as X-ray radiographs (such as chest X-ray, mammograms, etc.) must not be underestimated, as they offer cost-effective and reliable screening tools that often provide important diagnostic information sufficient to make correct diagnosis and judgment about the treatment.

However, in many critical radiological applications, the multi-dimensional visualization and quantitative analysis of physiological structures provide unprecedented clinical information extremely valuable for diagnosis and treatment. The ability of computerized processing and analysis of medical imaging modalities provides a powerful tool to help physicians. Thus computer programs and methods to process and manipulate the raw data from medical imaging scanners must be carefully developed to preserve and enhance the real clinical information of interest rather than introducing additional artifacts. The ability to improve diagnostic information from medical images can be further enhanced by designing computer processing algorithms intelligently. Often, incorporating relevant knowledge about the physics of imaging, instrumentation and human physiology in computer programs provides outstanding improvement in image quality as well as analysis to help interpretation. For example, incorporating knowledge about the geometrical location of the source, detector and patient can reduce the geometric artifacts in the reconstructed images. Further, the use of geometrical locations and characteristic signatures in computer-aided enhancement, identification, segmentation and analysis of physiological structures of interest often improves the clinical interpretation of medical images.

1.1 MEDICAL IMAGING: A COLLABORATIVE PARADIGM

As discussed above, with the advent and enhancement of modern medical imaging modalities, intelligent processing of multi-dimensional images has become crucial in conventional or computer-aided interpretation for radiological and diagnostic applications. Medical imaging and processing in diagnostic radiology has evolved with significant contributions from a number of disciplines including mathematics, physics, chemistry, engineering, and medicine. This is evident when one sees a medical imaging scanner such as a MRI or PET scanner. The complexity of instrumentation and computer aided data collection and image reconstruction methods clearly indicate the importance of system integration as well as a critical understanding of the physics of imaging and image formation (see Fig. 1.1). Intelligent interpretation of medical images requires understanding of the interaction of the basic unit of imaging (such as protons in MRI, or X-ray photons in X-ray CT) in a biological environment, formation of a quantifiable signal representing the biological information, detection and acquisition of the signal of interest, and appropriate image reconstruction. In brief, intelligent interpretation and analysis of biomedical images require an understanding of the acquisition of images.

A number of computer vision methods have been developed for a variety of applications in image processing, segmentation, analysis and recognition. However, medical image reconstruction and processing require specialized knowledge of a
specific medical imaging modality that is used to acquire images. The character of the collected data in the application environment (such as imaging the heart through MRI) should be properly understood for selecting or developing useful methods for intelligent image processing, analysis and interpretation. The use of application domain knowledge can provide useful help in selecting or developing the most appropriate image reconstruction and processing methods for accurate analysis and interpretation.

1.2 MEDICAL IMAGING MODALITIES

The field of medical imaging and image analysis has evolved due to the collective contributions from many areas of medicine, engineering and basic sciences. The overall objective of medical imaging is to acquire useful information about the physiological processes or organs of the body by using external or internal sources of energy [1–3]. Figure 1.2 identifies medical imaging modalities classified on the basis of energy source used for imaging. Imaging methods available today for radiological applications may use external, internal or a combination of energy sources (Figure 1.3). In most commonly used imaging methods ionized radiation such as X-rays are used as an external energy source primarily for anatomical imaging. Such anatomical imaging modalities are based on the attenuation coefficient of radiation passing through the body. For example, X-ray radiographs and Computed Tomography (X-ray CT) imaging modalities measure attenuation coefficients of X-ray that are based on the density of the tissue or part of the body being imaged. The images of chest radiographs show a spatial distribution of X-ray attenuation coefficients reflecting the overall density variations of the anatomical parts in the chest. Another example of external energy source based imaging is ultrasound or acoustic imaging. Nuclear Medicine imaging modalities use an internal energy source through an emission process to image the human body. For emission imaging, radioactive pharmaceuticals are injected into the body to interact with selected body matter or tissue to form an internal source of radioactive energy that is used for imaging. The emission imaging principle is applied in Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET). Such types
of Nuclear Medicine imaging modalities provide useful metabolic information about the physiological functions of the organs. Further, a clever combination of external stimulation on internal energy sources can be used in medical imaging to acquire more accurate information about the tissue material and physiological responses and functions. Magnetic Resonance Imaging uses external magnetic energy to stimulate selected atomic nuclei such as hydrogen protons. The excited nuclei become the internal source of energy to provide electromagnetic signals for imaging through the process of relaxation. Magnetic Resonance Imaging of the human body provides high-resolution images of the human body with excellent soft-tissue characterization capabilities. Recent advances in MRI have led to perfusion and functional imaging aspects of human tissue and organs [3–6]. Another emerging biophysiological imaging modality is fluorescence imaging, which uses an external ultraviolet energy source to stimulate the internal biological molecules of interest, which absorb the ultraviolet energy, become internal sources of energy and then emit the energy at visible electromagnetic radiation wavelengths [7].

Before a type of energy source or imaging modality is selected, it is important to understand the nature of physiological information needed for image formation. In other words, some basic questions about the information of interest should be answered. What information about the human body is needed? Is it anatomical,
physiological or functional? What range of spatial resolution is acceptable? The selection of a specific medical imaging modality often depends on the type of suspected disease or localization needed for proper radiological diagnosis. For example, some neurological disorders and diseases demand very-high-resolution brain images for accurate diagnosis and treatment. On the other hand, full-body SPECT imaging to study metastasizing cancer does not require sub-millimeter imaging resolution. The information of interest here is cancer metastasis in the tissue that can be best obtained from the blood flow in the tissue or its metabolism. Breast imaging can be performed using X-rays, magnetic resonance, nuclear medicine or ultrasound. But the most effective and economical breast imaging modality so far has been X-ray mammography because of its simplicity, portability and low cost. One important
source of radiological information for breast imaging is the presence and distribution of microcalcifications in the breast. This anatomical information can be obtained with high resolution using X-rays.

There is no perfect imaging modality for all radiological applications and needs. In addition, each medical imaging modality is limited by the corresponding physics of energy interactions with human body (or cells), instrumentation and often physiological constraints. These factors severely affect the quality and resolution of images sometimes making the interpretation and diagnosis very difficult. The performance of an imaging modality for a specific test or application is characterized by sensitivity and specificity factors. Sensitivity of a medical imaging test is defined primarily by its ability to detect true information. Let us suppose we have an X-ray imaging scanner for mammography. The sensitivity for imaging microcalcifications for a mammography scanner would depend on many factors including the X-ray wavelength used in the beam, intensity and polychromatic distribution of the input radiation beam, behavior of X-rays in breast tissue such as absorption and scattering coefficients, and film/detector efficiency to collect the output radiation. These factors would eventually affect the overall signal-to-noise ratio, leading to the loss of sensitivity of detecting microcalcifications. The specificity for a test depends on its ability to not detect the information when it is truly not there.

1.3 MEDICAL IMAGING: FROM PHYSIOLOGY TO INFORMATION PROCESSING

From physiology to image interpretation and information retrieval, medical imaging is a five-step paradigm. The five-step paradigm allows acquisition and analysis of useful information to understand the behavior of an organ or a physiological process.

1. Understanding Imaging Medium: The imaged objects (organs, tissues and specific pathologies) and associated physiological properties that could be used for obtaining signals suitable for the formation of an image must be studied for the selection of imaging instrumentation. This information is often very useful in designing image processing and analysis techniques for correct interpretation. The information about imaging medium may involve static or dynamic properties of the biological tissue. For example, tissue density is a static property that causes attenuation of an external radiation beam in X-ray imaging modality. Blood flow, perfusion and cardiac motion are examples of dynamic physiological properties that may alter the image of a biological entity. Due considerations of the dynamic behavior of the imaging medium is essential in designing compensation methods needed for correct image reconstruction and analysis. Motion artifacts pose serious limitations on data collection time and resolution in medical imaging instrumentation and therefore have a direct effect on the development of image processing methods.

2. Physics of Imaging: The next important consideration is the principle of imaging to be used for obtaining the data. For example, X-ray imaging modality uses transmission of X-rays through the body as the basis of imaging. On the other hand, in the nuclear medicine modality, Single Photon Emission
Computed Tomography (SPECT) uses the emission of gamma rays resulting from the interaction of a radiopharmaceutical substance with the target tissue. The emission process and the energy range of gamma rays cause limitations on the resolution and data acquisition time for imaging. The associated methods for image formation in transmission and emission imaging modalities are so different that it is difficult to see the same level of anatomical information from both modalities. The SPECT and PET imaging modalities provide images that are poor in contrast and anatomical details while the X-ray CT imaging modality provides sharper images with high-resolution anatomical details. The MR imaging modality provides high-resolution anatomical details with excellent soft-tissue contrast [6, 7].

3. Imaging Instrumentation: The instrumentation used in collecting the data is one of the most important factors defining the image quality in terms of signal-to-noise ratio, resolution and ability to show diagnostic information. Source specifications of the instrumentation directly effect imaging capabilities. In addition, detector responses such as non-linearity, low efficiency, long decay time and poor scatter rejection may cause artifacts in the image. An intelligent image formation and processing technique should be the one that provides accurate and robust detection of features of interest without any artifacts to help diagnostic interpretation.

4. Data Acquisition Methods for Image Formation: The data acquisition methods used in imaging play an important role in image formation. Optimized with the imaging instrumentation, the data collection methods become a decisive factor in determining the best temporal and spatial resolution. It is also crucial in developing strategies to reduce image artifacts through active filtering or post-processing methods. For example, in X-ray computed tomography, the spatially distributed signal is based on the number of X-ray photons reaching the detector within a time-interval. The data for three-dimensional imaging may be obtained using a parallel-, cone-, or spiral-beam scanning method. Each of these scanning methods causes certain constraints on the geometrical reconstruction of the object under imaging. Since the scanning time in each method may be different, spatial resolution has to be compromised with temporal resolution. This means that a faster scan would result in an image with a lower spatial resolution. On the other hand, a higher spatial resolution method would normally require longer imaging time. In dynamic studies where information about blood flow or a specific functional activity needs to be acquired, the higher resolution requirement is usually compromised. Image reconstruction algorithms such as Back-projection, Iterative and Fourier transform methods are tailored to incorporate specific information about the data collection methods and scanning geometry. Since the image quality may be affected by the data collection methods, the image reconstruction and processing methods should be designed to optimize the representation of diagnostic information in the image.

5. Image Processing and Analysis: Image processing and analysis methods are aimed at the enhancement of diagnostic information to improve manual or computer-assisted interpretation of medical images. Often, certain transformation methods improve the visibility and quantification of features of
Interactive and computer-assisted intelligent medical image analysis methods can provide effective tools to help the quantitative and qualitative interpretation of medical images for differential diagnosis, intervention and treatment monitoring. Intelligent image processing and analysis tools can also help in understanding physiological processes associated with the disease and its response to a treatment.

1.4 GENERAL PERFORMANCE MEASURES

Let us define some measures often used in the evaluation of a medical imaging or diagnostic test for detecting an object such as microcalcifications or a physiological condition such as cancer. A “positive” observation in an image means that the object was observed in the test. A “negative” observation means that the object was not observed in the test. A “true condition” is the actual truth, whereas an observation is the outcome of the test. Four basic measures are defined from the set of true conditions and observed information, as shown in Figure 1.4. These basic measures are True Positive, False Positive, False Negative and True Negative rates or fractions. For example, an X-ray mammographic image should only show the regions of pixels with bright intensity (observed information) corresponding to the microcalcification areas (true condition when the object is present). Also, the mammographic image should not show similar regions of pixels with bright intensity corresponding to the areas where there is actually no microcalcification (true condition when the object is not present).

Let us assume the total number of examination cases to be \(N_{\text{tot}}\), out of which \(N_{\text{tp}}\) cases have positive true-condition with the actual presence of the object and the remaining cases, \(N_{\text{tn}}\), have negative true-condition with no object present. Let us suppose these cases are examined though the test for which we need to evaluate accuracy, sensitivity and specificity factors. Considering the observer does not cause
any loss of information or misinterpretation, let $N_{otp}$ (True Positive) be the number of positive observations from $N_{tp}$ positive true-condition cases and $N_{otn}$ (False Negative) be number of negative observation from $N_{tp}$ positive true-condition cases. Also, let $N_{otn}$ (True Negative) be the number of negative observations from $N_{tn}$ negative true-condition cases and $N_{ofp}$ (False Positive) be number of positive observation from $N_{tn}$ negative true-condition cases. Thus

\begin{align*}
N_{tp} &= N_{otp} + N_{otn} \quad \text{and} \quad N_{tn} = N_{ofp} + N_{otn}.
\end{align*}

1. **True Positive Fraction** (TPF) is the ratio of the number of positive observations to the number of positive true-condition cases.

\[
\text{TPF} = \frac{N_{otp}}{N_{tp}}. \tag{1.1}
\]

2. **False Negative Fraction** (FNF) is the ratio of the number of negative observations to the number of positive true-condition cases.

\[
\text{FNF} = \frac{N_{otn}}{N_{tp}}. \tag{1.2}
\]

3. **False Positive Fraction** (FPF) is the ratio of the number of positive observations to the number of negative true-condition cases.

\[
\text{FPF} = \frac{N_{ofp}}{N_{tn}}. \tag{1.3}
\]

4. **True Negative Fraction** (TNF) is the ratio of the number of negative observations to the number of negative true-condition cases.

\[
\text{TNF} = \frac{N_{otn}}{N_{tn}}. \tag{1.4}
\]

It should be noted that

\[
\text{TPF} + \text{FNF} = 1; \\
\text{TNF} + \text{FPF} = 1. \tag{1.5}
\]

A graph between TPF and FPF is called a Receiver Operating Characteristic (ROC) curve for a specific medical imaging or diagnostic test for detection of an object. Various points on the ROC curve as shown a, b and c in Figure 1.5 shows different decision thresholds used for classification of the examination cases into positive and negative observations, and therefore defining specific sets of paired values of TPF and FPF. It should also be noted that statistical random trials with equal probability of positive and negative observations would lead to the diagonally placed straight-line as the ROC curve. Different tests and different observers may lead to different ROC curves for the same object detection.

True Positive Fraction, TPF, is also called the sensitivity, whereas the True Negative Fraction (TNF) is known as specificity of the test for detection of an object. Accuracy of the test is given by a ratio of correct observation to the total number of examination cases. Thus
In other words, different imaging modalities and observers may lead to different accuracy, sensitivity and specificity levels.

The accuracy, sensitivity and specificity factors are given serious considerations when selecting a modality for radiological applications. For example, the reason X-ray mammography is so successful in breast imaging is because it provides excellent sensitivity and specificity for imaging breast calcifications. While in neurological applications requiring a demanding soft-tissue contrast, magnetic resonance imaging provides better sensitivity and specificity factors than X-ray imaging.

1.4.1 Example of Performance Measure

Let us assume that 100 female patients were examined through the X-ray mammography test. The X-ray mammographic images were observed by a physician to classify into one of the two classes: normal and cancer. The objective here is to determine the basic performance measures of the X-ray mammography test for detection of breast cancer. Let us assume that all patients were also tested through tissue-biopsy examination to determine the true conditions. If the result of the biopsy examination is positive, then the cancer (object) is present as the true condition. If the biopsy examination is negative, then the cancer (object) is not present as the true condition. If the physician diagnoses the cancer from the X-ray mammography test, the object (cancer) is observed. Let us assume the following distribution of patients with respect to the true conditions and observed information:

1. Total number of patients = $N_{tot} = 100$;
2. Total number of patients with biopsy proven cancer (true condition of object present) = $N_{tp} = 10$;
3. Total number of patients with biopsy proven normal tissue (true condition of object NOT present) = $N_{tn} = 90$;

\[
\text{Accuracy} = \frac{(TPF + TNF)}{N_{tot}}. \tag{1.6}
\]

This equation represents the percentage of correctly classified cases out of the total number of cases. In other words, different imaging modalities and observers may lead to different accuracy, sensitivity and specificity levels.

Figure 1.5. ROC curves with curve “a” indicating better overall classification ability than the curve “b”, while the curve “c” shows the random probability.
4. Out of the patients with cancer \( N_{\text{tp}} \), the number of patients diagnosed by the physician as having cancer = Number of True Positive cases = \( N_{\text{otp}} \) = 8;

5. Out of the patients with cancer \( N_{\text{tp}} \), the number of patients diagnosed by the physician as normal = Number of False Negative cases = \( N_{\text{ofn}} \) = 2;

6. Out of the normal patients \( N_{\text{tn}} \), the number of patients rated by the physician as normal = Number of True Negative cases = \( N_{\text{otn}} \) = 85; and

7. Out of the normal patients \( N_{\text{tn}} \), the number of patients rated by the physician as having cancer = Number of False Positive cases = \( N_{\text{ofp}} \) = 5.

Now the True Positive Fraction (TPF), False Negative Fraction (FNF), False Positive Fraction (FPF) and True Negative Fraction (TNF) can be computed as

\[
\text{True Positive Fraction (TPF)} = \frac{8}{10} = 0.8.
\]
\[
\text{False Negative Fraction (FNF)} = \frac{2}{10} = 0.2.
\]
\[
\text{False Positive Fraction (FPF)} = \frac{5}{90} = 0.0556.
\]
\[
\text{True Negative Fraction (TNF)} = \frac{85}{90} = 0.9444.
\]

It should be noted that the above values satisfy the Equation (1.5) as

\[
\text{TPF} + \text{FNF} = 1.0 \quad \text{and} \quad \text{FPF} + \text{TNF} = 1.0
\]

1.5 BIOMEDICAL IMAGE PROCESSING AND ANALYSIS

A general-purpose biomedical image-processing and image analysis system must have three basic components: (1) an image-acquisition system, (2) a digital computer and (3) an image display environment. Figure 1.6 shows a schematic block diagram of a biomedical image processing and analysis system.

The image-acquisition system usually converts a biomedical signal or radiation carrying the information of interest to a digital image. A digital image is represented by an array of digital numbers that can be read by the processing computer and displayed as a two-, three- or multi-dimensional image. As introduced above, medical imaging modalities use different image-acquisition systems as a part of the imaging instrumentation. The design of the image-acquisition system depends on the type of modality and detector requirements. In some applications, the output of the scanner may be in analog form, such as a film-mammogram or a chest X-ray radiograph. In such applications, the image-acquisition system may include a suitable light source to illuminate the radiograph (film) and a digitizing camera to convert the analog image into a digital picture. Other means of digitizing an image include several types of microdensitometers, and laser scanners. There is a variety of sources of biomedical imaging applications. The data-acquisition system has to be modified accordingly. For example, a microscope can directly be hooked-up with a digitizing camera for acquisition of images of a biopsy sample on a glass slide. But such a digitizing camera is not needed for obtaining images from a X-ray CT scanner. Thus the image-acquisition system differs across applications.
The second part of the biomedical image-processing and analysis system is a digital computer with usually large memory units that are used to store digital images for further processing. A general-purpose computer or a dedicated array processor can be used for image analysis. The dedicated hard-wired image processors may be used for the real-time image-processing operations such as image enhancement, pseudo-color enhancement, mapping, and histogram analysis.

A third essential part of the biomedical image-processing and analysis system is the image display environment, where the output image can be viewed after the required processing. Depending on the application, there may be a large variation in the requirements of image display environment in terms of display capabilities such as resolution grid size, number of gray-levels, number of colors, split-screen access, and so forth. There might be other output devices such as hard-copy output machine or a printer that can also be used in conjunction with the regular output display monitor.

For an advanced biomedical image analysis system, the image display environment may also include a real-time image-processing unit which may have some built-in processing functions for quick manipulation. The central image-processing unit, in such systems, does the more complicated image processing and analysis only. For example, for radiological applications, the image display unit should have a fast and flexible environment to manipulate the area of interest in the image. This manipulation may include gray-level remapping, pseudo-color enhancement, zoom-in, and/or split-screen capabilities, to aid the attending physician to see more diagnostic information right away. This type of real-time image processing may be taken as a part of the image-display environment in a modern sophisticated image analysis system that is designed for handling the image analysis and interpretation tasks for biomedical applications (and many others). The display environment, in such systems, includes one or more pixel processors or point processors (small processing units or single-board computers) along with a number of memory planes, which act as buffers. These buffers or memory planes provide a very efficient means of implementing a number of Look-Up-Tables (LUTs) without losing the original image data. The specialized hardwired processing units including dedicated processors are accessed and communicated with by using the peripheral devices such as keyboard, data-tablet, mouse, printer, and high-resolution monitors.
There are several image-processing systems available today which satisfy the usual requirements (as discussed above) of an efficient and useful biomedical image analysis system. All these systems are based on a special pipeline architecture with an external host computer and/or an array processor, allowing parallel processing and an efficient communication among various dedicated processors for real-time or near real-time split-screen image manipulation and processing performance. Special-purpose image-processing architectures including array processors, cellular logic and Field Programmable Logic Arrays (FPGA).

As discussed above, every imaging modality has limitations that affect the accuracy, sensitivity and specificity factors, which are extremely important in diagnostic radiology. The imaging systems called scanners are usually equipped with instrumentation to provide external radiation or energy source (as needed) and measure an output signal from the body. The output signal may be an attenuated radiation or another form of energy-carrying information about the body. The output signal is eventually transformed into an image to represent the information about the body. For example, an X-ray mammography scanner uses an X-ray tube to generate a radiation beam that passes through the breast tissue. As a result of the interactions among X-ray photons and breast tissue, the X-ray beam is attenuated. The attenuated beam of X-ray radiation coming out of the breast is then collected on a radiographic film. The raw signals obtained from instrumentation of an imaging device or scanner are usually pre-processed for a suitable transformation to form an image that makes sense from the physiological point of view and is easy to interpret. Every imaging modality uses some kind of image-reconstruction method to provide the first part of this transformation for conversions of raw signals into useful images. Even after a good reconstruction or initial transformation, images may not provide useful information with a required localization to help interpretation. This is particularly important when the information about suspect objects is occluded or overshadowed by other parts of the body. Often reconstructed images from scanners are degraded in a way that without changing the contrast and brightness, the objects of interest may not be easily visualized. Thus an effective and efficient image-processing environment is a vital part of the medical imaging system.

Since the information of interest about biological objects often is associated with characteristic features, it is crucial to use specially designed image-processing methods for visualization and analysis of medical images. It is also important to know about the acquisition and transformation methods used for reconstruction of images before appropriate image-processing and analysis algorithms are designed and applied. With the new advances in image processing, adaptive learning and knowledge-based intelligent analysis, the specific needs of medical image analysis to improve diagnostic information for computer-aided-diagnosis can be addressed.

Figure 1.7(a)–(b) shows an example of feature-adaptive contrast enhancement processing as applied to a mammogram to enhance microcalcification areas. Figure 1.7(c) shows the result of a standard histogram equalization method commonly used for contrast enhancement in image processing. It is clear that standard image-processing algorithms may not provide help in medical image processing. Specific image-processing operations are needed to deal with the information of radiological interest. The following chapters will introduce fundamental principles of medical
imaging systems and image-processing tools. The latter part of the book is dedicated to the design and application of intelligent and customized image-processing algorithms for radiological image analysis.

1.6 EXERCISES

1.1. Is it necessary to understand the physics and instrumentation of medical imaging modality before processing the data for image reconstruction, processing and interpretation? Give reasons to support your answer.
1.2. What are the measures for evaluation of a medical imaging modality?

1.3. Explain the significance of the Receiver Operating Characteristic (ROC) curve?

1.4. A chest phantom was implanted with different sizes and types of nodular lesions and was imaged with a new X-ray scanner. Let us assume that there are 156 radiographs of the chest phantom screened for detection of nodular lesions. The radiographs showed 44 lesions out of which 4 lesions were verified to be false. The radiographs also missed 3 lesions that could not be seen by an observer. Compute accuracy, sensitivity and specificity of the X-ray scanner in imaging nodular lesions in the chest.
1.5. As compared to image-processing methods used in general picture processing, do you think medical image processing methods should be customized based on the physics of imaging and properties of the imaging medium? Explain your answer.

1.6. MATLAB: Display an image of a breast mammogram from the MAMMO database. Apply histogram equalization, Sobel’s mask and adaptive feature enhancement methods for contrast enhancement. Compare the enhanced images to original image qualitatively.

1.7. MATLAB: Repeat Exercise 1.6 for a MRI of the brain from the MRIBRAIN database. Do you see the same type of enhancement effect in each method for two images from different imaging modalities? Look for edge and object definitions in the original and enhanced images. Also, comment on the saturation and noise artifacts in the enhanced images.

1.7 REFERENCES


1.8 DEFINITIONS

**Accuracy:** Accuracy is the ability to measure a quantity with respect to its true value. This is the difference between measured value and true value divided by true value.

**Precision:** The precision of a measurement expresses the number of distinguishable values or alternatives from which a given result is elected. Precision makes no comparison to the true value. Therefore high precision does not mean high accuracy.

**Resolution:** The smallest incremental quality that can be measured with certainty is the resolution.

**Reproducibility:** The ability to give the same output for equal inputs applied at different times is called reproducibility or repeatability. Reproducibility does not imply accuracy.

**Sensitivity:** The sensitivity of a test is the probability of its yielding positive results when a given condition is true. For example, sensitivity of a diagnostic test for a
disease is the probability of detecting positive outcome when the disease is present. This is also provided in terms of True-Positive Fraction (TPF). A test with high sensitivity will have a low False-Negative Fraction (FNF), that is, the probability of not being able to detect the positive outcome when the disease was present. TPF + FNF = 1.0.

**Specificity:** The specificity of a test is the probability of its yielding negative results in patients who do not have a disease. This is also provided in terms of True Negative Fraction (TNF). A test with high specificity will have low False-Positive Fraction (FPF).