
Computational Medical Imaging Analysis

Chapter 1: Introduction to Imaging Science

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1.1a: Introduction

- Biological organisms, including humans, depend on the continuous movements of fluids to supply nutrition and carry away waste
- Fluid movements are actuated and controlled by voluntary or involuntary musculature
- Function of muscle cells is determined by their atomic constituency, biochemical nature, metabolic characteristics, and geometric arrangements
- There is a need for improved understanding of the normal and pathophysiological processes by using visualizing and measuring these anatomic structures and functional variables

1.1b: Means for Visualization

- It is desirable that visualization and measurements of bodily organs and tissues do not affect their working environment, i.e., to be noninvasive
- They should involve minimum possible degree of morphological and physiological disturbance
- Transmission of radiant energy, e.g., X-rays, gamma ray, radio waves, or ultrasound waves, etc. through body produces images without subjective sensation and does not directly affect the function of bodily tissues at some dose levels for useful images
- Images are produced by differential absorption and scatter pattern of radiant energy by different tissues in all body parts

1.2a: X-ray

- In 1895, Wilhelm Conrad Rontgen, a German physicist at the University of Wurzburg made the great discovery of the invisible ray
- First radiograph of hand made with ray from fluorescence using cathode ray tubes
- X-ray made it possible to “see into the body” in a painless, nondestructive way
- This discovery was quickly recognized and accepted as a new medical diagnostic technique
- Modest, but acceptable, risks are incurred due to the ionizing effect of the X-rays

1.2b: Wilhelm Conrad Röntgen (1901 Nobel Prize in Physics)



1.2c: Developments Following X-ray

- The discovery of X-ray spurred a succession of evolutionary improvements in radiographic instrumentation and photographic procedures
- In 1940, introduction of fluoroscopic imaging with an image intensifier (with a television) – dynamic X-ray imaging systems
- In 1950, nuclear medicine tomographic imaging
- In 1960, ultrasonography
- The basic radiographic process used by Rontgen had not changed very much for more than 75 years

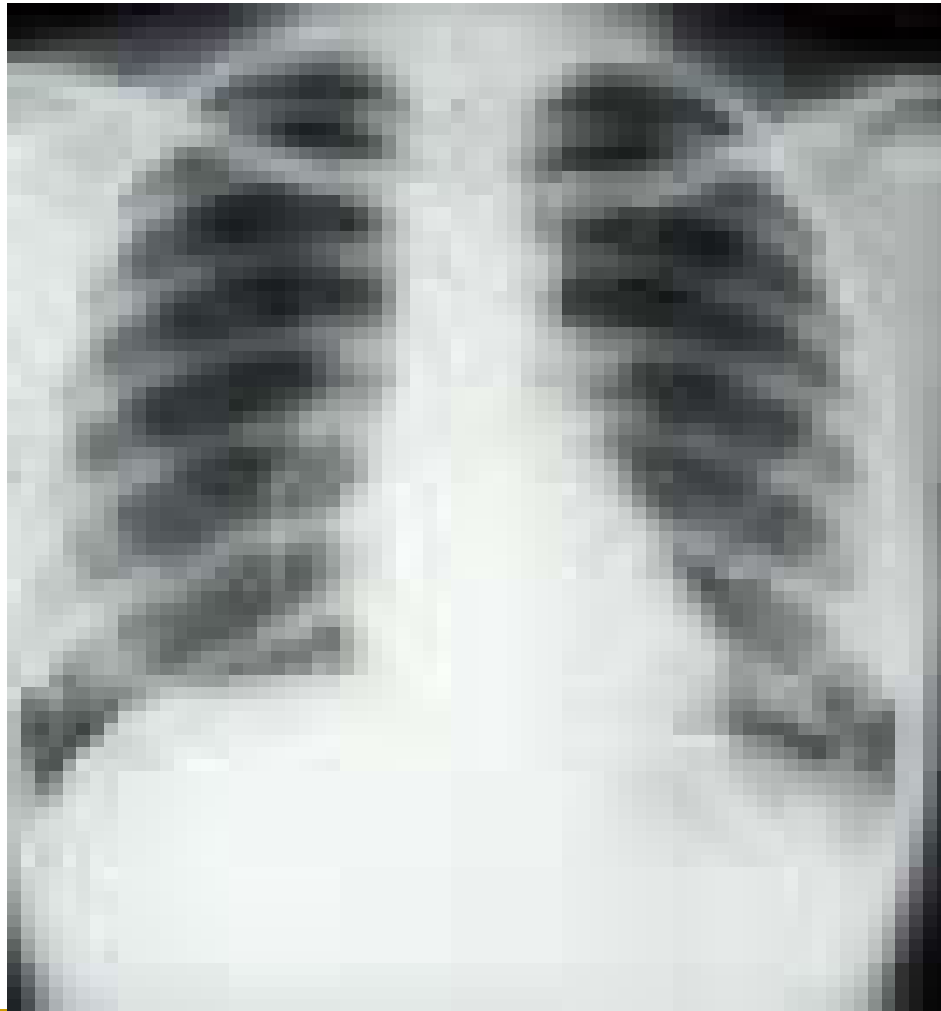
1.2d: Medical Use of X-ray

- Detection and delineation of diseases
- Clear photographs of internal body structures
- Rapid imaging systems can produce dynamic recordings of internal moving organs
- Contrast angiography, injection of radiopaque substances into the bloodstream, enables visualization of circulation to, from, and within almost any organ of the body

1.2e: Limitations of X-ray

- Small characteristic differences (1% to 2%) in X-ray attenuation by various body tissues are not detectable on the film
- A large percentage of the radiation detected is scattered from the body, reducing signal-to-noise ratio of the recorded information
- Much detail is lost in the radiographic process due to the superposition of 3D structural information onto a 2D detector
- Image quality improvements in 75 years are mainly due to the improvement in X-ray film, not the X-ray technology or procedure

1.2e* X-ray Superposition



1.2f: X-ray Computed Tomography (CT)

- Transaxial scanning, with a highly collimated rotating X-ray source, coupled with computer-based image reconstruction techniques, provides unambiguous images of cross-sectional dimensions of the body
- CT eliminated or greatly minimized the problem of superposition and differential attenuation of X-ray
- Won Nobel Prize in Physiology and Medicine in 1979 for Allan Macleod Cormack and Godfrey Newbold Hounsfield

1.2g: Other 3D Imaging Modalities

- Magnetic resonance imaging (MRI)
- Positron emission tomography (PET)
- Functional MRI (fMRI)
- Diffusion tensor MRI (DT-MRI)
- All require fast imaging acquisition and computer-assisted reconstruction for true 3D images
- Multidimensional, multimodality imaging with near-simultaneous multienergy scanning methods, using two or more different radiant energies to improve specificity and sensitivity in clinical diagnosis

1.3a: Definitions and Fundamental Issues

- The process of forming an image involves the mapping of an object, and/or some property of an object, onto the “image space”
- **Imaging science** is defined as the study of these mappings and development of ways to better understand them, to improve them, and to productively use them
- Biomedical imaging and visualization is directed toward productive use of imaging science, and involves the acquisition, transformation, and presentation of and interaction with multidimensional medical and/or biological data sets

1.3b: Three-dimensional Imaging

- **Three-dimensional** imaging refers to acquiring digital samples of objects distributed throughout three-space, usually but not necessarily with isotropic spacing. The term may also include processing, displaying, and analyzing such 3D data sets
- A 3D image may be synthesized by appropriate successive 2D steps, but ideally is acquired simultaneously in three-dimension and the imaging process (function) is applied congruently in three dimensions

1.3c: Multimodal Imaging

- **Multimodal imaging** refers to the use of different imaging systems (e.g., CT, MRI, PET) to acquire images of the same object, providing complementary and more complete information about the object than can be obtained from any single image type
- It may be used to describe a spatio-temporo “fusion” of images of the same object obtained from different imaging systems, determined by spatially and/or temporally registering the different images with sophisticated mathematical algorithms

1.3d: Real-time Imaging or Visualization

- **Real-time imaging** refers to image data or collection rates that are considered real time, that is, 30 images per second
- In computer display applications, real time implies a frame refresh/update rate sufficiently high to avoid perception of “jerkiness” or stutter, generally at 15 to 30 frames per second
- Display systems must compute and display each new image or view in approximately 75 milliseconds or less

1.3d: Interactive Visualization

- Refers to sufficiently high response and repetition rate of the system, which senses a user action of some type (e.g., mouse movement, keystroke, wand motion) and computes a corresponding result so that the user will perceive (near) instantaneous response to his or her actions (such as fMRI)
- Requires a response/repetition rate of 10 to 20 responses per second
- Higher rates are needed for highly dynamic situations, lowers rates for more static activities

1.3e: Three-dimensional Visualization

- Refers to transformation and display of 3D objects to effectively represent the 3D nature of the objects
- 3D visualization can be rendered as volume graphics on 2D display devices, or stereoscopic-type displays requiring no physical aids, or “immersive” displays that project the viewer “into” the scene, such as in a virtual reality environment
- 3D visualization here includes the ability to manipulate and analyze the displayed information, and may imply inclusion of cognitive and interpretive elements

1.3f: The Imaging Science Disciplines

- With the advent of inexpensive and powerful computers, three important disciplines of medical imaging science have emerged since 1980s
 1. Segmentation
 2. Registration
 3. Visualization

1.3g: Segmentation

- **Segmentation** is the important yet elusive capability for accurate recognition and delineation of all individual objects in an image scene
- The boundaries between different objects need to be delineated
- In medical images, it is sometimes important to extract a certain tissue or organ from the images for visualization or analysis

1.3h: Registration

- **Registration** involves finding the transformation that brings different images of the same object(s) into strict spatial (and/or temporal) congruence
- This is mostly used in group comparison to find the common basis for comparison
- Images of the same object taken at different time need to be registered so that they can be compared on the same basis

1.3i: Visualization

- **Visualization** includes display, but also manipulation and mensuration of image data
- Visualization can be on 2D display devices or with some other special aiding equipments for “immersive” display
- Note that visualization is not necessarily to display the original raw data, it may involve sophisticated procedures or techniques to make the display more visually attractive

1.3j: 3D Imaging Software

- There is a growing market for useful 3D imaging software
- It must be comprehensive, be directed toward relevant problems, and highly operator responsive
- It should be really useful, must produce realistic displays, generate precise and accurate quantitative measurements, and allow useful editing and manipulation of the objects being imaged or displayed