A Very Fast Introduction to Medical Imaging

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Fundamentals

- Imaging systems are designed, used, and evaluated by first deciding on a purpose: a task.
- Physicians are taught to translate disease processes into image contrast (radiological anatomy: biology to physics and technology).
- Select a modality based on engineering (sensitivity, specificity, spatial resolution, SNR).
- Evaluation of observer performance includes balance among diagnostic efficacy, costs, and risks (benefit to cost ratio).
Projection X-ray

Contrast: mass density and atomic number differences
X-ray Computed Tomography

Anatomy of a CT scan
CT scanners give doctors a 3-D view of the body. The images are exquisitely detailed but require a dose of radiation that can be 100 times that of a standard X-ray. Computed tomography scans are made by rotating an X-ray beam around the patient, imaging the body in a series of slices that a computer stitches together.

CT scan machine
Motorized platform
Patient lies on motorized platform
Rotating X-ray detectors
Fan-shaped X-ray beam
Rotating X-ray source
Direction of rotation
Stationary Detector Ring
5s
Matlab simulation of X-ray CT

P=phantom(128);
subplot(2,2,1);imshow(P,[]),title('original')
R = radon(P,0:179);
subplot(2,2,2);imshow(R,[]),title('sinogram')
P1=iradon(R,0:179);
subplot(2,2,3);imshow(P1,[]),title('filtered BP')
P2=iradon(R,0:179,'linear','none');
subplot(2,2,4);imshow(P2,[]),title('unfiltered BP')
Magnetic Resonance Imaging (MRI)

3 research-dedicated magnets, covering small mice to humans

• 14.1 T Small bore, Ultra high-field, 10 μm resolution

• 3 T Siemens Allegra
  22 cm FOV, head-only scanner
  High performance gradients

• 3 T Siemens Trio
  50 cm FOV, Whole body scanner
  Multinuclear Spectroscopy: beyond water
  \( ^3\text{He}, ^7\text{Li}, ^{13}\text{C}, ^{17}\text{O}, ^{19}\text{F}, ^{23}\text{Na}, ^{31}\text{P}, ^{129}\text{Xe} \)
Contrast from…

- Proton density, T1 relaxation, T2 relaxation, chemical species, flow, diffusion, blood oxygenation, temperature changes, magnetic susceptibility (degree of magnetization when body is placed in a magnetic field)
- Type of sequence chosen and protocol parameters can lead to different contrasts in different acquisitions.
Fourier encoding also works in 2 and 3 dimensions:

2D Imaging - 2D Fourier Transform
Low Spatial Frequencies

2D FT
MRI: Many different views of physiology

Structural

Mechanical Properties

Functional

Metabolic Imaging

Perfusion, Blood flow/volume

NAA

Lactate
X-ray vs sonography

(a) Source and detector

(b) Tomographic image plane $(x_1, x_2)$

Projection image plane $(x_2, x_3)$
Contrast mechanisms

- Surfaces of density and compressibility fluctuations (B-mode contrast); e.g., cells, nuclei, ECM, vessels
- Variations in scatterer movement (Doppler imaging, elasticity imaging)
- Contrast may be enhanced using nano- or micro-scale air bubbles
1-D Linear Arrays

Transmission

- Pulse emissions
- Sound beam
- Tissue scatterer
- Piezoelectric elements

Reception

- Beamformed RF echo signals
- Transmission Reception
- P-Amp
- TGC
- AA-LPF
- ADC
- Tx BF and HV Pulser
- Delay
- ADC
- AA-LPF
- TGC
- P-Amp
- Diplexer
- Apodization
- From array element
- To be summed
- Trig
Beamforming

https://www.youtube.com/watch?feature=player_detailpage&v=SrUoXkKoREE
Dealing with Aberrations

• The effect of aberration correction algorithms
Color Flow Information Overlay

Color-flow imaging: mean pulsed Doppler velocity overlaid upon B-mode anatomical image to indicate velocity: magnitude and direction of blood flow

Power-Doppler imaging: net pulsed Doppler velocity overlaid upon B-mode anatomical image: magnitude of blood flow
Image Rendering and Display

Color flow Ultrasonic Imaging

3-D Ultrasonic Imaging
Contrast mechanisms

- Surfaces of density and compressibility fluctuations (B-mode contrast)
- Variations in scatterer movement (Doppler imaging, elasticity imaging)
- Contrast may be enhanced using nano- or micro-scale air bubbles
Contrast media for targeted drug delivery
Summary

- Medical imaging requires a deep understanding of topics in physics, math, EE, physiology, molecular biology, CS => BIOE. Topics range from sources, detectors, system design, signal & image processing => linear systems.
- Begin by identifying the task, then find a modality sensitive to those features. *Acquire* as much patient information as you can and *display* it in a form accessible by the trained human eye-brain detector.
- Evaluation of imaging systems is statistical: no two patients or radiologists are the same, so need to average. Observer performance, ROC analysis, etc.