INTRODUCTION TO MEDICAL IMAGING

ULAS BAGCI, PHD
ASSIST. PROF. OF CRCV,
COMPUTER SCIENCE, UNIVERSITY OF CENTRAL FLORIDA,
ORLANDO, FL. 32816

BAGCI@CRCV.UCF.EDU
PRELIMINARY CHECK

• X-ray imaging ?
• Ultrasound ?
• Computed Tomography (CT) ?
• Magnetic Resonance Imaging (MRI) ?
• Positron Emission Tomography (PET) ?
MEDICAL IMAGING

• The most direct way to see inside the human (or animal) body is cut it open (i.e., surgery).

• With medical imaging methods, we can see inside the human body in ways that are less invasive (or completely non-invasive).

• We can even see metabolic/functional/molecular activities which are not visible to naked eye.

• Image—a 2D signal $f(x,y)$ or 3D $f(x,y,z)$
MAJOR IMAGING MODALITIES

• X-ray (projection): Radiography
• Computed Tomography (CT)
• Nuclear Medicine (SPECT, PET)
• Ultrasound (US)
• Magnetic Resonance Imaging (MRI)
ANY ASSOCIATED RISKS?

- X-ray (projection): Radiography
- Computed Tomography (CT)
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RADIATION

NO HARM AT ALL
X-RAY IMAGING - RADIOGRAPHY

• The first published medical image was a radiograph of the hand of Wilhelm Conrad Roentgen’s wife in 1895. Nobel Prize in Physics 1901.

• routine diagnostic radiography:
  
  • chest x-rays, fluoroscopy, mammography, and motion tomography, angiography, …
X-RAY IMAGING (RADIOGRAPHY)

X-rays absorbed by dense part of the body

X-RAYS: A FORM OF ELECTROMAGNETIC ENERGY TRAVEL AT THE SPEED OF LIGHT

Photographic plate or digital detector

1. Fat
2. Gas/air
3. Calcified (bone)
4. Tissues
PROJECTION X-RAY IMAGING

Transmissivity of body vs. EM spectrum Energy

- MRI
- Near IR
- diagnostic x-ray band

X-ray source → object → x-ray detector

above diagnostic band: body is too transparent
below diagnostic band: body is too opaque
there is no depth info (z)!

line/projection integral
BASIC USES OF X-RAY IMAGING

- Dental examination
- Surgical markers prior to invasive procedures
- Mammography
- Orthopedic evaluations
- Fluoroscopy
- Tuberculosis/lung cancer/…
- Forensic age estimation (by left hand)
X-RAY IMAGING-CLINICAL USE

PELVIS

ELBOW

HAND

FOREARM

Shoulder, a-p X-ray:
1: Acromial end of clavicle
2: Acromion
3: Humeral head
4: Epiphyseal scar
5: Anatomical neck
6: Greater tubercle
7: Lesser tubercle
8: Coracoid process
9: Surgical neck
10: Glenoid cavity
11: Neck of scapula
12: Lateral border of scapula
13: Spine of scapula
14: First rib
15: Superior angle of scapula
16: Medial border of scapula
17: Sternal end of clavicle
18: Manubrium of sternum
19: Sternal angle
20: Body of sternum
21: Inferior angle of scapula
X-RAY IMAGING—HOW DO RADIOLOGISTS INTERPRET?

Bening calcification patterns

- Diffuse
- Central
- Popcorn
- Laminar, Concentric

potentially malignant patterns

- Stippled
- Eccentric
Example of parenchymal mass (right hilum)

Difficulties

1. noise
2. vessels can be seen as small nodules
3. radiologists may miss the pattern
4. patterns may not be diagnostic
5. CT often required for better diagnosis
6. size estimation is done by manually in 2D
7. shadowing
8. total lung capacity computation

Computer aided methods can solve/simplify these problems for improved healthcare (NEXT LECTURE!!!)
X-RAY IMAGING - HOW DO RADIOLOGISTS INTERPRET?

- Multiple small nodules
- Mass
- Malignant tumor (breast cancer)
- Benign tumor
WHERE DO RADIOLOGISTS INTERPRET SCANS?

- Dedicated light source
- Darkened environment
- Limited distraction
SAMPLE USE OF CAD SYSTEMS IN QUANTITATIVE IMAGE ANALYSIS
ULTRASOUND IMAGING

US is defined as any sound wave above 20KHz

1794-Lazzaro Spallanzani - Physiologist
First to study US physics by deducing bats used to US to navigate by echolocation.

1826-Jean Daniel Colladon - Physicist
Uses church bell (early transducer) under water to calculate speed of sound through water prove sound traveled faster through water than air.

1880-Pierre & Jacques Curie
Discover the Piezo-Electric Effect (ability of certain materials to generate an electric charge in response to applied mechanical stress.)
ULTRASOUND IMAGING

1942-Karl Dussik - Neurologist
First physician to use US for medical diagnosis

1948-George Ludwig - MD
First described the use of US to diagnose gallstones

1958-Ian Donald
Pioneers in OB-GYN
PRINCIPLES OF ULTRASOUND IMAGING

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First physician to use US for medical diagnosis
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US equipment assumes that sound velocity is constant in the body.

<table>
<thead>
<tr>
<th>Body tissue</th>
<th>Acoustic impedance ($10^5$ Rayls)</th>
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<tbody>
<tr>
<td>Air</td>
<td>0.0004</td>
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<tr>
<td>Lung</td>
<td>0.18</td>
</tr>
<tr>
<td>Fat</td>
<td>1.34</td>
</tr>
<tr>
<td>Liver</td>
<td>1.65</td>
</tr>
<tr>
<td>Blood</td>
<td>1.65</td>
</tr>
<tr>
<td>Kidney</td>
<td>1.63</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.71</td>
</tr>
<tr>
<td>Bone</td>
<td>7.8</td>
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</table>
FEATURES OF ULTRASOUND IMAGING

• Resolution:
  • direction of pulse propagation, pulse width 1-2mm
  • direction of scanning: beam width 2-3mm
  • low resolution and low SNR in deep region
• Ability of imaging soft tissue
• imaging in real time
• Doppler image
• Artefacts

Color flow mapping shows simultaneous amplitude (US) and velocity information (doppler)
When ultrasound passes through two very different materials the majority of it is reflected. This happens between air and the body, meaning that most ultrasound waves never enter the body. To prevent this large difference in impedance a coupling medium (gel) is used between the air and the skin. The need to match up similar impedances to ensure the waves pass through the body is known as impedance matching.
CLINICAL USES OF ULTRASOUND

fetal US

pancreas tumor (1cm)
Renal artery blood flows

Can computer help calculating all blood flow and identify automatically the abnormal regions? (See Next Lecture, afternoon)

Stenosis is seen

eca: external carotid artery
cca: common carotid artery
ica: internal carotid artery
BONE, FAT, AND LENGTH MEASUREMENTS OF INFANTS WITH ULTRASOUND
COMPUTED TOMOGRAPHY (CT)

1979-Sir Godfrey N. Hounsfield
Nobel prize winner, from Nottingham.
Hounsfield -> HU
COMPUTED TOMOGRAPHY (CT)

parallel beam  
fan beam  
cone beam

A  Sagittal  
B  Coronal  
C  Axial
C-ARM COMPUTED TOMOGRAPHY (CT)
3D NATURE OF COMPUTED TOMOGRAPHY (CT)

Axial

Sagittal

Coronal
VOLUME RENDERING - SEMI QUANTITATIVE MEASUREMENTS AND VISUALIZATION
VOLUME RENDERING - SEMI QUANTITATIVE MEASUREMENTS AND VISUALIZATION

How about surface rendering? (require precise image segmentation Next lecture)
HYBRID RENDERING - QUANTITATIVE
ABNORMAL IMAGING PATTERNS IN CT FOR DIAGNOSING LUNG DISEASES

(A) Normal
(D) Fibrosis

(B) Emphysema
(E) Micronodules

(C) Ground Glass Opacity
(F) Consolidation
DIFFERENT WINDOWING FOR LUNG AND SOFT TISSUE CONTRAST

(a) lung window

(b) soft tissue
SHORT AND LONG AXIS TUMOR MEASUREMENT (MANUALLY)

2D measurement                      severity association
CARDIAC CT - CLINICAL USE

HOW TO CALCULATE THE AMOUNT OF FLUID?

ITS EXTENSION?

AND DIAGNOSIS?
ABDOMINAL CT - CLINICAL USE

RENAL STONES
TUMORS
FUNCTIONAL ABNORMALITIES
ETC..

LIVER
KIDNEY
ANYTHING INTERESTING IN THIS SCAN?
ANYTHING INTERESTING IN THIS SCAN?
MAGNETIC RESONANCE IMAGING (MRI)

1882-Nichola Tesla
Discovered rotating magnetic field

1971-Paul Lauterbur  NOBEL PRIZE
First invented MRI

Late 1970-Sir Peter Mansfield (Nottingham)  NOBEL PRIZE
Developed mathematical techniques to create clearer images and also in minutes rather than hours as Lauterbur did.

• CT is more widely used than MRI.
• MRI does not have ionizing-radiation.
• MRI has excellent soft tissue contrast, while CT is preferred for lung and bone imaging.
• CT is fast (few seconds), while MRI is slow (sparse MRI ~5-10 mins, abdomen or brain may take 30-40 mins).
MAGNETIC RESONANCE IMAGING (MRI)
PHYSICS OF MAGNETIC RESONANCE IMAGING (MRI)

no magnetization
PHYSICS OF MAGNETIC RESONANCE IMAGING (MRI)

A
“Slice” selection

B
The X-Y selecting gradients

Phase encoding gradient

Frequency encoding gradient
SAFETY OF MRI!
TYPES OF MR IMAGING

T1, T2, PD, fMRI, DTI, DWI

T2: decay of transverse magnetization
TE: echo time
T1: recovery of long. magnetization
TR: time to wait for re-sampling
TYPES OF MR IMAGING

TE

<table>
<thead>
<tr>
<th>Long</th>
<th>Short</th>
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</thead>
<tbody>
<tr>
<td>PROTON DENSITY</td>
<td>T1-WEIGHTED</td>
</tr>
<tr>
<td>T2-WEIGHTED</td>
<td></td>
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TYPES OF MR IMAGING
TYPES OF MR IMAGING: DWI AND DTI

- measures random Brownian motion of water molecules.
- useful for tumor characterization (densely cellular tissues exhibit lower diffusion).

DTI

- allow measurement of water molecules’ diffusion
- provide connectivity of neural tracks
Glioblastoma tumor
TYPES OF MR IMAGING: DTI

[Images and tables related to DTI (Diffusion Tensor Imaging) are shown, including plots and data tables.]
TYPES OF MR IMAGING: DTI
CLINICAL USE OF MRI

Picker MR Scanner
CLINICAL USE OF MRI

- Sacrum
- L5-S1 disc
- Herniated disc
- Thecal sac

- High signal from fat in spinal canal surrounding thecal sac and nerve roots
- Right S1 nerve root
CLINICAL USE OF MRI

myocardial infarction
CLINICAL USE OF MRI

RECTAL TUMOR
FUNCTIONAL MRI (FMRI)

- measures brain activity through oxygen concentration in the blood flow.
- relies on the fact that cerebral blood flow and neuronal activation are coupled.
- when area of the brain is active (in use), blood flow to that area also increases.

- which part/location of the brain is activated when reading?
- which part/location of the brain is activated when listening music?
- which part/location of the brain is activated when searching puzzle?
FUNCTIONAL MRI (FMRI)

Normal

Mild cognitive impairment

Alzheimer's disease
NUCLEAR IMAGING - PET/SPECT

**Scint:** Scintigraphy, two-dimensional images

**PET:** Positron Emission Tomography

**SPECT:** Single Photon Emission Tomography
NUCLEAR IMAGING - PET/SPECT

1,650,000 Clinical PET and PET-CT Studies in 2010 (US Statistics)

- Diagnosis: 33%
- Staging: 38%
- Treatment Planning: 10%
- Therapy Followup: 19%
BASICS OF PET IMAGING

• uses short-lived positron emitting isotopes (produced by collimators)
• two gamma rays are produced from the annihilation of each positron and can be detected by specialized gamma cameras
• resulting image show the distribution of isotopes
• an agent is used to bind into isotopes (glucose, ...)

Late 1950s, David L. Kuhl
concept of emission and transmission molecular activity is measured.
HYBRID IMAGING TECHNOLOGIES

PET/CT
-choice of modality for oncological applications (yet)

MRI-PET
-superior soft tissue contrast resolution
-minimized radiation
QUANTIFICATION - WHAT TO MEASURE IN PET?

- **SUV** (standardized uptake value: voxel-wise or region-wise) (SUVpeak, SUVmax, SUVlbm)

- Metabolic lesion/tumor volume (MTV)

- **Shape** information of (functional) lesion (spiculated vs focal)

- **Texture** information of lesion (heterogeneous vs homogeneous)

- **Number and distribution** of the lesions (focal, multi-focal)
CLINICAL USES OF PET
CLINICAL USES OF PET-SURGERY PLANNING
CLINICAL USES OF PET-SURGERY PLANNING
MRI/PET OF SPINE AND BREAST
SERIAL AND SIMULTANEOUS MRI/PET
## COMPARISON OF IMAGING METHODS

<table>
<thead>
<tr>
<th></th>
<th>CHEST</th>
<th>ABDOMEN</th>
<th>HEAD</th>
<th>CARDIOVASCULAR</th>
<th>SKELETAL/MUSCULAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CT</strong></td>
<td>CT: GOLD STANDARD</td>
<td>NEED CONTRAST FOR EXCELENCY, WIDELY USED</td>
<td>GOOD FOR TRAUMA</td>
<td>GOLD STANDARD</td>
<td>GOLD STANDARD</td>
</tr>
<tr>
<td><strong>US</strong></td>
<td>NO USE, EXCEPT HEART</td>
<td>PROBLEMS WITH GAS</td>
<td>POOR</td>
<td>POOR</td>
<td>ELASTOGRAPHY</td>
</tr>
<tr>
<td><strong>NUCLEAR</strong></td>
<td>EXTENSIVE USE IN HEART AND THERAPY IN LUNG</td>
<td>CT OR MRI IS MERGED</td>
<td>PET</td>
<td>PERFUSION</td>
<td>BONE MARROW</td>
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<tr>
<td><strong>MRI</strong></td>
<td>GROWING CARDIAC APPLICATIONS</td>
<td>INCREASED ROLE OF MRI</td>
<td>GOLD STANDARD</td>
<td>WILL REPLACE CT IN NEAR FUTURE</td>
<td>EXCELLENT</td>
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BREAK...