Principles of Medical Ultrasound

Pai-Chi Li
Department of Electrical Engineering
National Taiwan University
What is **Medical Ultrasound**?

- **Prevention**: actions taken to avoid diseases.
- **Diagnosis**: the process of identifying a disease by its signs, symptoms, and results of various diagnostic procedures.
- **Treatment**: care by procedures or applications that are intended to relieve illness or injury.
Diagnosis
Medical Diagnosis: Heart Attack as an Example

- Heart attack: Coronary artery disease, blockage of blood supply to the myocardium.
Medical Diagnosis: Heart Attack as an Example

- Plaque: A gradual buildup of fat (cholesterol) within the artery wall.
Medical Diagnosis: Heart Attack as an Example

• Symptoms:
  – Chest pressure with stress, heart burn, nausea, vomiting, shortness of breath, heavy sweating.
  – Chest pain, heart attack, arrhythmias.
Medical Diagnosis: Heart Attack as an Example

• Diagnosis:
  – Prehospital electrocardiography (ECG).
  – Continuous/serial ECG.
  – Exercise stress ECG.
  – Biochemical tests and biomarkers.
  – Sestamibi myocardial perfusion imaging.
  – Echocardiography.
  – Computer-based decision aids.
Doppler Tissue Imaging
Doppler Tissue Imaging

- Tissue velocity imaging
- Derivation in space
- Strain rate imaging
- Integration in time

- Tissue tracking imaging
- Integration in space
- Strain imaging
- Integration in time
Doppler Tissue Imaging
Treatment
Controlled Ultrasound Tissue Erosion

• Hypoplastic left heart syndrome (HLHS).
Ultrasound Cardiac Ablation

IBI Ultrasound Ablation System
IBI Ultrasound Generator with Ultrasound Catheter (Steerable Shaft) showing inflated Transducer at Distal End.
Medical Diagnosis: Heart Attack as an Example

• Treatment:
  – Angioplasty.
  – Stent implantation.
  – Atherectomy.
  – Coronary bypass surgery.
  – Intravascular radiotherapy.
  – Excimer laser.
Medical Diagnosis:
Heart Attack as an Example

- Imaging:
  - Ultrasound.
Medical Diagnosis: Heart Attack as an Example

• Imaging:
  – Optics.
What is Medical Ultrasound?

- **Wave**: various propagation modes (longitudinal, shear, ...etc.).
- **Mechanical wave**: density, elastic properties, ...etc.
- **Wave**: scattering, diffraction, refraction, ...etc.
- **Mechanical wave**: heating, cavitation, ...etc.
Bio-Effects

- Heating
- Cavitation
Ultrasound Heating

- Bio-transfer equation:
  \[
  \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} + \omega_b \rho_b c_b (T_a - T) + Q_m + Q_r(x,t)
  \]
Bio-Effects

- Heating
- Cavitation
Cavitation

- Formation and behavior of gas bubbles in acoustic fields.
- Transient cavitation: sudden growth and collapse of bubbles, resulting shock waves and very high temperatures.
Other Acoustic Phenomena

• Radiation force.
• Sonoluminescence.
• …etc.
Radiation Force

• An ultrasonic wave exerts a static force on an interface or in a medium where there is a decrease in power in the wave propagation direction.
Other Acoustic Phenomena

- Radiation force.
- Sonoluminescence.
- …etc.
Sonoluminescence

- Weak emission of light observable when high intensity ultrasound passing through a medium containing dissolved gases.
...,etc.
History of Ultrasound
*Who are the smart guys?*
History of Ultrasound

- A long time ago:
History of Ultrasound

• A long time ago:
History of Ultrasound

• 1822, Lake Geneva:
History of Ultrasound

• Piezoelectric effect, Pierre Curie, 1880:
History of Ultrasound

• 1947, Karl Dussik:
History of Ultrasound

• 1954-1957:
History of Ultrasound

- 1954-1957:
History of Ultrasound

- Doppler (1842):
History of Ultrasound

- Doppler ultrasound (1959-1960):
History of Ultrasound

The water-bag B-mode scanning system, the SSD-1, from Aloka in 1960

Sound-wave portrait in the flesh
History of Ultrasound
History of Ultrasound
History of Ultrasound
Overview of Ultrasonic Imaging
The AcuNav Diagnostic Ultrasound Catheter
Clinical Applications

- OB/GYN, vascular, cardiac, transcranial, abdominal, musculoskeletal, endo-vaginal, endo-rectal, ocular, intra-vascular, ...etc.

(From www.acuson.com)
Characteristics of Diagnostic Ultrasound

- Non-invasive.
- Safe (under regulations).
- Real-time.
- Reflection mode (similar to RADAR).
- Blood flow imaging.
- Access.
- Portable.
- Body type dependent.
Characteristics of Diagnostic Ultrasound

• Spatial resolution:
  – Lateral and elevational: diffraction limited.
  – Axial: transducer and system bandwidth, pulse energy.

• Contrast resolution: spatial resolution and speckle brightness variations.

• Temporal resolution: speed of sound in tissue.

• Tissue inhomogeneities.
Function Modes

- A-mode (A-scan, 1D).
- B-mode (Gray scale, 2D).
- 3D ultrasound.
- M-mode (motion)
- Color Doppler (2D, blood flow).
- Spectral Doppler (localized, blood flow).
- Audio Doppler.
A-Scan (Amplitude, 1D)
B-Scan (Brightness, 2D)
Scan Formats

linear

sector

curved linear

easy access
limited view

limited access
wide view

wide view

easy access
wide view
3D Ultrasound
M-Mode (Motion)
Ultrasonic Transducers
Ultrasonic Array Transducers

(From www.acuson.com)
Doppler Techniques for Motion Estimation
Color Doppler Mode
Power Doppler
PW Doppler (Spectral Doppler)
CW Doppler (Spectral Doppler)
Doppler Effect
Blood Flow Measurements

PRI (pulse repetitive interval)
Generic Ultrasonic Imaging System

- Transmitter:
  - Arbitrary waveform.
  - Programmable transmit voltage.
  - Arbitrary firing sequence.
  - Programmable apodization, delay control and frequency control.

Digital Waveform Generator → D/A → HV Amp → Transducer Array

Control
Generic Ultrasonic Imaging System

• Receiver:
  – Programmable apodization, delay control and frequency control.
  – Arbitrary receive direction.

• Image processing:
  – Pre-detection filtering.
  – Post-detection filtering.

• Full gain correction: analog and digital.

• Scan converter: various scan format.
Principles of Medical Ultrasound

- Physics
- Phenomena
- Imaging technologies
- System implementation
- Signal processing
- Biomedical relevance