Biomechanics of Living Tissues and Organs

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Simulation of Medical Procedures

Procedures to be Simulated

- Palpation
- Incision
- Cutting
- Catheter insertion
- ...

Biomechanical Problem

Loading via tool → Tissue Model → Deformation
e.g. Displacement at contact point, (d)
Force on the tool, (f)

Boundary conditions
Simulation Accuracy

What is needed depends on:
• Goals of the training task
• Trainee’s perceptual and motor abilities

What is achieved depends on:
• Limitations of tissue models and software algorithms
• Limitations of computational speed and display devices
Complexities in Accurate Simulation

- Tool-organ contact mechanics
- Large deformations
- Friction conditions
- Temperature
- Dynamics
- Incision
- Cutting

- Extent
- Geometry
  - Irregular 3D
  - Homogeneous, layered, .......
- Material properties
  - Homogeneity
  - Anisotropy
  - Non-linearity
- Boundary/interface condition specification
- Organ-organ contact mechanics

Display modes
- Graphics (30Hz update)
- Haptics (1kHz update)
Force Response of the Human Fingerpad to Indentation

Tactile Stimulator Setup

Model of Force Response

Model Predictions (black) vs. Experimental Data (grey) for Cylindrical Indenter
Approximations in Simulation

- Point or line contact
- Small deformations
- Ignore friction, temperature effects
- Quasi-static conditions

- Restricted extent
- Simplified geometry
- Homogeneous, isotropic, linear material properties
- Idealized boundary/interface conditions
- Ignore organ-organ contact mechanics

Model updates can be slower than display refresh rates
Essential Tissue/Organ Physical Properties

- Elasticity - Young’s modulus
- Compressibility - Poisson’s ratio
- Viscosity - damping coefficient
- Density - mass/unit volume
- “Strength” - piercing, cutting
- Organ boundary conditions
Measurements of Tissue/Organ Physical Properties

• In vitro on excised tissue
• Cadaver - needs to be fresh
• In vivo with instrumented tools - animals
  - humans
Stimuli for Physical Property Measurements

- Ramp and hold - tensile or compressive
- Sinusoidal vibrations
- White noise / pink noise
- .............
Inferring Tissue Elemental Properties

Determine model parameters that match (e.g. Young’s modulus, Poisson’s ratio)

Experimental Data

Loading via tool → Tissue/organ model

Deformation

Force on the tool

e.g. particle model, “waterbed” model, finite element model
Tactile Sensory System
(Data mainly for the fingerpad)

Absolute detection threshold
- 20 um @ static
- 10 um @ 10 Hz
- 0.1 um @ 250 Hz

Pressure threshold - 0.3 mN/mm²
Feature detection
- 0.1 um for texture
- 2 um for single dot

Temporal resolution - 10 ms between two taps
Frequency range - 1 kHz
Frequency resolution - 10% to 80%

Spatial resolution
  localization - 0.15 mm
  2-point limen - 1 mm
### Kinesthetic Sensory System

- **Position resolution**: 1° to 2° at joints
  - 0.5 mm at fingertip
- **Position reproduction**: 5° to 10°
- **Bandwidth**: 20 to 30 Hz

### Motor System

**Motion:**
- **Range of motion**: 20° to 100°
- **Velocity**: 0.1 m/s at fingertip
  - 1 m/s at wrist
- **Bandwidth**
  - unexpected signals: 1 to 2 Hz
  - periodic signals: 2 to 5 Hz
  - reflex action: 10 Hz

**Forces:**
- **single finger**
  - typical range: 1 to 10 N
  - controllable range: up to 100 N
  - control resolution: 0.05 to 0.5 N
  - grasp force range: 50 to 100 N
Active touch including tactile, kinesthetic, and motor systems

Resolution (JND)
- Length: 10% or less
- Velocity: 10%
- Acceleration: 20%
- Force: 7%

Compliance
- Rigid surface (e.g. piano key): 8%
- Deformable surface (e.g. rubber): 3%
- Viscosity: 14%
- Mass: 21%

Rigidity perception: 25 N/mm or greater
With conflicting visual and haptic cues, perceived stiffness of virtual spring depends on visual not haptic feedback.

2-Alternative Forced Choice; JND = 10%
Actual Stiffness Difference held constant at 50%
All visual feedback via computer monitor.