Virtual Reality System for Transurethral Resection of the Prostate with Haptic Interaction

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*La Medicina Incontra la Realtà Virtuale.*

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Transurethral Resection of the Prostate
Computer Assisted Training

- **Shorter** training periods;
- Cost effective training;
- Computer simulated environment with visual and physical **realism**;
- **Simulation of real events**: sound, bleeding, coagulation, optics, tissue texture, tissue resection, tactile sensation, vital signs;
- Database of clinical cases;
- Simulation of **risky tasks** and unexpected situations;
- **Patient-specific** simulation for training or planning;
- Measurement and evaluation of **medical skills**;
- Active training by haptic robotic guidance for **skills transfer**;
TURP Surgery Simulator

Mechatronic Resectoscope

- Loop
- Pennile urethra
- Prostate
- Bladder
- Resectoscope
- Loop Control
- Movements

Virtual Environment
The Mechatronic Interface

Schematic lateral view of the Interface with the prostate phantom

I) Disk-ring array and optical digital encoders for sensing rotational axes of the resectoscope;
II) Degrees of freedom, where a and b are linear, c, d and e are rotational;
III) Hall effect sensors array for controlling the Resecting loop.
The Signal Acquisition System

- **Four PIC’s 16F876A** for digital signals (3 for monitoring **optical sensors**, 1 for multiplexing data);

- **LP3500** as master card and for analog signals (**hall effect sensors and linear potentiometer**).
3D Modelling of the Prostate

Image Acquisition

Transurethral ultrasound images (Point Distribution Model and a Genetic Algorithm)

Shape interpolation by Morphing

Delaunay Tetrahedrization

Distance Map

3D Adaptive Sampling
3D Modelling of the Prostate
Virtual Environment

Visible Human Database

- Male
- Female
- Bladder reconstruction (Triangular mesh)

Pennile urethra

- Sphincter

Bladder

Prostate & coagulation
Two important landmarks during a TURP Surgery, are the sphincter and the bladder neck.

A portion of the model of urethra was configured as deformable.
Collision Response and Deformation

- After a collision is detected the soft tissue must deform;

- Mass-spring method for deformable behaviour:

  \[ m_i \frac{d^2 x_i}{dt^2} + \gamma_i \frac{dx_i}{dt} + g_i(t, x_i) = f_i(t, x_i) \]

  \( m_i \) - mass of the node \( N_i \);
  \( x_i \) - coordinates of \( N_i \);
  \( \gamma_i \) - damping coefficient of \( N_i \);
  \( g_i \) - Internal elastic force over \( N_i \);
  \( f_i \) - External force over \( N_i \).

- Deformations result from the reacting forces (depending of the penetration):

  \[ f_i = \frac{p_n}{N(i)} \sum_{j \in N(i)} \mu_{i,j} \]

  \( \mu_{i,j} \) - stiffness of the spring \( N_i \), \( N_j \);
  \( p \) - Penetration
  \( n \) - Normal of the contact point \( N_i \).

- Penetration field is computed from the collision history;

- Distance Field as measure of penetration.

Penetration stops after critical response rate (100 Hz)
3D (mass-springs) Modelling of the Prostate
Collision Detection

At each recursion a Bounding-Box that covers the leaf spheres is computed;
Spheres are divided through the orthogonal plane placed at the middle of the Principal Component of the box.

Collision Detection Algorithm

Object 1

Object 2

Stops after critical time (300 Hz)
GPU Computing

- Haptic response?
- Sensors
- Movements
- Vertices
- Data Structures
  - Collision
  - Reacting forces
  - Texturing
- Virtual World
- Deformation:
  \[ m_i \frac{d^2 \mathbf{x}_i}{dt^2} + \gamma_i \frac{d \mathbf{x}_i}{dt} + \mathbf{g}_i(t, \mathbf{x}_i) = \mathbf{f}_i(t, \mathbf{x}_i) \]

- on CPU 65 Hz on, GPU at least 250 Hz

¡ +30 Hz!
Passive vs active feedback

Haptic Robot for Tactile Sensation (Sensable Phantom)
Current & Future Work

- Fast Tissue Resection;
- Accurate Haptic feedback;
- Construction of a Workstation Prototype;
- Integration of Realistic Sound;
- Visual Modelling of Bleeding points, bubbles, smoke;
- Medical evaluation (passive vs haptic interfaces)
Grazie mille!
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