Needle Placement Robots

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Why Percutaneous?

• Potentially significant impact on medical practice
  • Minimally invasive (compared to open surgery)
    • Faster recovery
    • Less morbidity
    • Fewer complications
    • Lower cost
    • Repeatable in many indications
  • Sharply increasing number of procedures

• Engineering opportunities and challenges
  • “Needle puncture” process well characterized
  • Right mix of simplicity and complexity
  • Major challenges:
    • no visibility
    • no access
    • no room to maneuver
    • no room to recover
## Clinical Scope of Our Investigation

<table>
<thead>
<tr>
<th>Prostate</th>
<th>Liver</th>
<th>Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td>200,000 cancers/year</td>
<td>Metastasis from colorectal cancer</td>
<td>$120 billion cost</td>
</tr>
<tr>
<td>1M biopsies /year</td>
<td>130,000 new /year</td>
<td>70% of population affected in lifetime</td>
</tr>
<tr>
<td>10M BPH currently</td>
<td>60,000 death /year</td>
<td>Bone</td>
</tr>
<tr>
<td>25% of men affected</td>
<td>Hepatitis worldwide</td>
<td>400,000 metastatic cases /year</td>
</tr>
<tr>
<td>in lifetime</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Why these?
- Societal impact in US and worldwide
- Clinical buy-in
- Pre-existing experience
- Suitable mix for prototype CIS engineering

*United States numbers*
Our vision: “Point & Click Surgery”

- Physician
- Planning & control computer
- Digital images
- Robot
- Imager
- Patient
- Coordinates
Neuromate (ISS)
IGOR (Lavallee, Troccaz, et al)
Hippocrate Robot E. Degoulange, *et al*
Serial Robots
Where all joints move at all times

Pros:
• Can move virtually anywhere
• Lots of different motions
• Smooth motion
• Can work like human limbs

Cons:
• Hard to constrain
• Safety concerns
• Complex control
• Ugly math
• Aggregating errors from each joint
Decoupled Robots
Where joints can move selectively

Pros:
- Separates steps of surgery
- Easy to constrain
- Simpler control
- Simpler Math
- Small errors

Cons:
- Limited types of motions
- Limited trajectory
- Feels like Tin Man from Oz
Kinematic Sequence for Needle Placement

Remote Center of Motion Concept
- Stationary fulcrum point
- Invented by Russ Taylor at IBM

Benefits
- Suits workflow
- Safe
- Modular

1. 3D translation “move needle to entry”
2. 2D Rotation “orient needle”
3. 1D/2D Insertion “drive needle”
Remote Center of Motion (RCM)

- 2 DOF rotation
- Mechanically constrained motion center

R. Taylor, D. Stoianovici, L. Whitcomb, A. Barnes
Remote Center of Motion (RCM)
Alternate RCM implementations:

- Parallel linkages
- Goniometer arcs

Mitsuishi, et al.
Chain drive RCM

- No friction
- No backlash
- 2x360° range
- 1.6 kg
- 20 cm
3DOF combo

- 7-DOF passive arm
- Needle
- Locking arm
- 2-DOF Remote Center of Motion robot
- 1-DOF needle injector w/ mounted stereotactic fiducials
- Joysticks and safety switches
- Amplifier box
- Table side robot mount
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Robotic prostate biopsy in CT scanner
Robotic prostate biopsy in CT scanner
Robotic prostate biopsy in CT scanner
Intra-operative treatment planning
Intra-operative treatment planning

Credit: Attila Tanacs
Transfer to kidney biopsy
Robot registered to CT from a single image using stereotactic frame on the end-effector

Photos: D. Stoianovici, L. Kavoussi, A. Patriciu, S. Solomon (JHU Bayview)
Other contributors: R. Susil, G. Fichtinger, K. Masamune, R. Taylor (JHU WSE)
Transfer to lung biopsy...
Robot registered to CT using the scanner’s alignment laser

Credit: D. Stoianovici, L. Kavoussi, A. Patriciu, S. Solomon, JHU Bayview
Robotic brachytherapy with US guidance
Replace the patient with phantom
The system

- Patient
- Robot
- Computer
- Operator
- Ultrasound
The robot

- 7-DOF passive arm
- 2-DOF rotation motion stage
- 1-DOF Needle insertion stage
- 3-DOF Cartesian motion
- Mounting bridge
- Ultrasound probe
- Ultrasound stepper

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Insertion of Tilted Needles

![Image of insertion of tilted needles with labels for patient, robot, ultrasound probe, and needle.]
Intra-operative Display
Intra-operative Display
Intra-operative Display
Steady Hand microsurgery robot

R. Taylor, D. Stoianovici, L. Whitcomb, A. Barnes
SteadyHand microsurgery robot – inner ear surgery
RCM in ultrasound: Salcludean ultrasound robot
Goldberg’s US robot
Robot-Assisted Volume Scans
In-MRI prostate surgery robot

- Closed MRI scanner
- Robotic Device
- Patient

Targeting parameters

Physician

Visualization and Targeting Program

Digital images

Physician Interface

MRI Scanner computer

Position Parameters

Real-time Tracking System
Where is the prostate?
Robotic Device: Degrees of Freedom

1. Rotation
2. Translation
3. Insertion

Biopsy gun

Transrectal probe with curved needle channel

Prostate
Why Use MRI?

• Good tissue contrast. MRI has excellent sensitivity for detecting tissue abnormalities.
• May allow for ‘targeted’ biopsy and improved diagnostic sensitivity
Technical challenges

• Small space inside scanner \(\rightarrow\) Dexterity

• High magnetic field \(\rightarrow\) Material compatibility
  • No metal (VIDEO1 VIDEO2)
  • No electronics

• Real-time imaging/tracking

• Curved needle placement \(\rightarrow\) Actuation
Full view of the robot

- Needle driver
- Stationary rectal sheath
- Positioning mechanism (rotates & translates needle guide)
- Positioning arm
In-vivo canine experiments

Six dogs so far
Results: Brachytherapy Seed Placement

Trocar tip

Canula

Brachytherapy seed
Brachytherapy Seed Placement (1)

Target

Needle Placement

Seed Placement

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Pushing the limits in many aspects

All-plastic robot

Acts inside the body

Needle turns a corner

Real-time tracking

Integrated Point&Click System

Control computer

Physician

Digital images

Closed MRI scanner

Robot

Patient

MRI Scanner computer

Smart Needle

Coaxial line

RF ablator + MRI antenna

Local imaging
THE END

Questions?

Comments?