Planning Challenges in Medical Robotics

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MRS NSF Workshop on Planning
Overview

Challenges

Interplay of Planning

Planning Challenges

Planning beyond Robots
Decrease costs

Reduce post-operative discomfort

Disseminate care
MIS Landscape

Intracavity Space
- Laparoscopy
- Arthroscopy
- Pericardioscopy
- Thoracoscopy

Superficial
- Colposcopy
- Cystoscopy
- Laryngoscopy

Deep in Anatomy
- Tracheoscopy
- ERCP
- Bronchoscopy
- Proctoscopy
- Gastroscopy

Intraluminal Pathways

Opportunity for Robotic Impact
<table>
<thead>
<tr>
<th>Challenges in Medical Robotics</th>
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<tbody>
<tr>
<td><strong>Access</strong></td>
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<tr>
<td><strong>Work/Tools</strong></td>
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</table>
### Why is planning hard for medical robots?

<table>
<thead>
<tr>
<th>Anatomy is densely packed</th>
<th>Lots of constraints</th>
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<tbody>
<tr>
<td>Maneuvering through tissue</td>
<td>Soft</td>
</tr>
<tr>
<td>Tissue moves</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Imaging not precise / control off</td>
<td>Uncertainty</td>
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<tr>
<td>Cant do harm / no killer app</td>
<td>Safety</td>
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Motion Planning

Types of Planning Needed

<table>
<thead>
<tr>
<th>Planning Type</th>
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<tbody>
<tr>
<td>Highly constrained spaces</td>
</tr>
<tr>
<td>High DOF / large C-space</td>
</tr>
<tr>
<td>Dynamic Planning</td>
</tr>
<tr>
<td>Planning under uncertainty</td>
</tr>
<tr>
<td>Optimal planning</td>
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</tbody>
</table>

2. Sensorless Motion Planning for Medical Needle Insertion in Deformable Tissues: Ron Alterovitz, Kenneth Y. Goldberg, Jean Pouliot, and I-Chow (Joe) Hsu, 2009
4. Motion planning and synchronized control of the dental arch generator of the tooth-arrangement robot: Jin-Gang Jiang, Yong-De Zhang, 2012
8. Motion planning in stereotaxic radiosurgery: Schweikard, Achim, John R. Adler, and J-C. Latombe, 1993

Simaan (2009)

http://robotics.cs.unc.edu/SteerableNeedles
Highly Constrained Environments

Curvature constrained paths to multiple goals for needle steering
Lobaton et al. (2012)

Task oriented design for concentric tube robots
Torres et al. (2012)

3D Motion planning for steerable needles
Duindam et al. (2010)

Dupont (2011)
Planning for Large C-Spaces

Novel Robots

Planners

Planning and control of steerable needles, Reed et al. (2006)

Randomized kinodynamic planning

Motion Planning for Active Cannulas, Lyons et al. (2009)
Planning with Deformations

Alterovitz et al. (2005)

Rodriguez et al. (2006)

Moll and Kavraki (2006)
Planning Hierarchy

• High Level Plans
  – Sequence of operations to achieve task
    • (1) Make access ports at location A, B ad C
    • (2) insert tool P
    • (3) Remove tissue at point C, so on so forth

• Mid/Low level Plans
  – Plans paths/trajectories
    • find obstacle free path from point A to B on feature
    • find path to remove material from region A
  – Plan motion to move along desired path
    • Underactuated and flexible systems need this
Beyond Planning for the Robot

Tasks beyond planning

Planning beyond the robot
<table>
<thead>
<tr>
<th>Task Challenges beyond Planning</th>
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<tbody>
<tr>
<td><strong>Mechanism Design</strong></td>
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<tr>
<td><strong>Kinematics</strong></td>
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<tr>
<td><strong>Planning</strong></td>
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<tr>
<td><strong>Estimation</strong></td>
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<tr>
<td><strong>Machine learning</strong></td>
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<tr>
<td><strong>Sensor development (MEMS)</strong></td>
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<tr>
<td><strong>Information technology</strong></td>
</tr>
<tr>
<td><strong>Sequencing / Execution</strong></td>
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</tbody>
</table>
Mechanism Design

**Challenges**

- Small Volume
- Range of motion
- Strength

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2. Design and control of motion compensation cardiac catheters: Kesner, Samuel B., and Robert D. Howe, 2005
5. Preliminary evaluation of a mobile robotic device for navigation and intervention on the beating heart: Patronik, N. A., M. A. Zenati, and C. N. Riviere, 2005

---

Webster (2009)

Simaan (2013)

Choset (2006)

Wolf (2005)

Hannaford

Whitcomb (2005)
Perception

**Challenges**
- Feature extraction
- Model fitting to pre-operative data
- Image segmentation
- Narrow field of view

**There too many list here!**


2. Laser-pointing endoscope system for intra-operative 3D geometric registration: Hayashibe, Mitsuhiro, and Yoshihiko Nakamura, 2001


Oesophagus (view from endoscope)


Human Robot Interaction

**Challenges**

Planning virtual fixtures
Motion compensation
Haptic feedback
Human intent recognition

1. Active compliance in robotic surgery—the use of force control as a **dynamic constraint**: Davies, B. L., S. J. Harris, W. J. Lin, R. D. Hibberd, R. Middleton, and J. C. Cobb, 1997
INTERPLAY: Closed Loop Interventional Medicine

**Information**
- Patient-specific Information (Images, lab results, genetics, etc.)
- General information (anatomic atlases, statistics, rules)

**Process Loop**
- Statistical Analysis

**Patient-specific loop**
- Patient-specific Evaluation

**Model**

**Plan**

**Action**

**Thanks to Rus Taylor**
Beyond Planning for the Robot

Tasks beyond planning

Planning beyond the robot
Image Guided Radiotherapy

- Radiation source mounted on robotic arm
- Automatic segmentation of targets
- Automated planning radiation beam path
- Image guide patient motion compensation for more accurate radiation targeting

Latombe (1999)
Planning Virtual Constraints for Bone Sculpting

NavioPFS (Blue Belt Inc.):
- CT-free imaging
- Uses data collected intra-operatively
- Allows the surgeon to prepare a surgical plan
- Generates real-time plan of cut surfaces
- Prepares predefined boundaries for target area

Patents:
Blue Belt: Navigated freehand surgical tool and kit (2011)
Planning Implant Location

- Pre-operative 3D model from CT scan
- Visualization of joint with implant
- Implant location and size planned using surgeon input to match desired outcome (rom, leg length)

*ROBODOC was the first medical robot!*

Patents:
Method and system for registering the position of a surgical system with a preoperative bone image. Brent D. Mittelstadt (1997)
Port Placement Planning

Cannon et al. (2003)

Adhami et al. (2000)
3D Printing

Rumored 3D printed implants for radiotherapy

Golderg (2014)

RP for planning of pulmonary stent implants

Armilotta et al. (2007)

Radiotherapy planning and verification

Sun and Wu (2004)
## Trends in Medical Robotics

<table>
<thead>
<tr>
<th>MIS</th>
<th>NOTES</th>
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<tr>
<td>SPA</td>
<td>HALS</td>
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## Medical Robotics Companies

<table>
<thead>
<tr>
<th>Company</th>
<th>Product/Technology</th>
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<tr>
<td>Intuitive Surgical</td>
<td>Da Vinci Surgical System</td>
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<td>Medrobotics</td>
<td>Snake Robot (Howie)</td>
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<tr>
<td>MAKO Surgical</td>
<td>Robotic Arm Interactive Orthopedic System</td>
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<tr>
<td>Hansen Medical</td>
<td>Robotic Catheter for cardiology</td>
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<tr>
<td>Titan Medical</td>
<td>Single Port Orifice Robotic Technology</td>
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<tr>
<td>Prosurgics</td>
<td>FreeHand</td>
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<tr>
<td>Accuray</td>
<td>CyberKnife Robotic Radiosurgery System</td>
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<td>IMRIS Inc.</td>
<td>NeuroArm</td>
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<td>Bluebelt</td>
<td>Knee implant</td>
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<tr>
<td>Conclusion</td>
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<tr>
<td><strong>Many planning challenges</strong></td>
<td><strong>Interplay with other tasks</strong></td>
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<tr>
<td><strong>More than just robots</strong></td>
<td><strong>We can lead</strong></td>
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Many planning challenges
Interplay with other tasks
More than just robots
We can lead

“Partnership in Interventional Medicine”

Human
Technology
Information

SKILLED TASK