Imaging Guided Medical Robotics

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Why medical robotics?

• Miniaturized & remote
  – More precise – less collateral damage
  – Less Invasive
  – Faster recovery

• Previously impossible treatments?

www.asme.org
Challenge: Visible light cannot interrogate inside Opaque organs & tissues.

- **Targeting:** Where to send the robot?
  - Many diseases are *internal* inside solid organs
  - Body is *opaque* to visible light
  - Many are localized to one spot
  - Most organs and abnormalities don’t have a predictable location

- **Device visualization:** Is the robot in the desired configuration?

- **Monitoring:** Is the robot having the desired therapeutic effect on the target tissues?
Solution: Imaging

• Energy Transmission: X-Ray, Scintigraphy
  – Most tissues are transparent to the method
  – Target “visible” on projections through the body

• Tomography of Energy-tissue interactions: CT, PET, MR, Ultrasound
  – Information gathered in slices / sections

• “Virtual Reality”: Extrapolated from device position.
  – EM tracking, spatial encoding, etc.
Types of Imaging

- X-Ray
- 99mTc Mag-3 Scintigraphy
- Ultrasonography
- X-Ray CT
- T2 MRI
Virtual Reality “Proprioceptive” imaging

- Computer-generated maps from EM-tracking of a catheter tip when contacts the wall of the left atrium. Each contact point “expands” the map “balloon”.

Carto3 Biosense Webster

- Path of an EM-trackable feeding tube tip as it advances down the esophagus, through the stomach and into the duodenum.

Coretrak2, Corpak MedSystems
# Pros & Cons of Imaging Modalities

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Benefits</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>X-Ray</td>
<td>• Most tissues are transparent</td>
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<tr>
<td></td>
<td>• Very Fast</td>
<td>• Ionizing Radiation</td>
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<tr>
<td></td>
<td>• High spatial resolution</td>
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<tr>
<td>CT</td>
<td>• Tomographic – 3D</td>
<td>• Ionizing Radiation</td>
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<tr>
<td></td>
<td>• Pretty fast</td>
<td>• Modest soft-tissue discrimination</td>
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<tr>
<td>US</td>
<td>• Tomographic</td>
<td>• Speckle</td>
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<tr>
<td></td>
<td>• No ionizing radiation</td>
<td>• Requires acoustic window</td>
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<tr>
<td></td>
<td>• Very fast, low cost</td>
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<tr>
<td>MRI</td>
<td>• Tomographic</td>
<td>• Artifacts from air, metal, motion, RF interference</td>
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<td></td>
<td>• Excellent soft-tissue contrast</td>
<td>• Magnet dangers</td>
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<tr>
<td>PET/ Scintigraphy</td>
<td>• Specific tracers image targets at low concentration</td>
<td>• Ionizing radiation</td>
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<tr>
<td></td>
<td></td>
<td>• Tissues are transparent</td>
</tr>
<tr>
<td>Virtual Reality</td>
<td>• Very fast, cheap</td>
<td>• Custom devices</td>
</tr>
<tr>
<td></td>
<td>• No radiation. 3D</td>
<td>• Only* shows device</td>
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Case

• ~45 y/o woman without symptoms
• Father had a mastectomy 10 years ago for breast cancer
• Niece just diagnosed with breast cancer

• What to do?
X-Ray mammography
Ultrasonography

RT BREAST
ENTIRE MEDIAL BREAST
NIPPLE TO PERIPHERY
NO 1 CM LESION SEEN
MRI - Guided Biopsy
Effect of caliber and materials on needle artifacts on MRI

MRI-compatible Breast Biopsy System
Case summary

- Roles for imaging:
  - Screening
  - Guidance
- Some modalities are more sensitive than others
  - MR Imaging found occult cancer at small size
- Early detection improves outcome in breast cancer
Challenge: Devices can interfere with Imaging

- MRI is most sensitive to artifacts from devices.
- CT and Ultrasound are also blocked by some devices.
Magnetic Implant Injection Port
MRI: RF interference

Axial Spin Echo

Sawyer-Glover / Lucas Center / Stanford
CT Artifacts from Metal Hip prostheses: Beam hardening and scatter.

US Artifacts from Ice around a cryoprobe.
Challenge: Device function in the imaging environment

This floor buffer might not bwork any more ...
Challenge: Risks of Imaging

- Ionizing Radiation (X-ray) - DNA damage
  - Decreased cell proliferation
  - Mutagenesis
  - Teratogenesis
- Heating (MRI, US)
- Peripheral Nerve Stimulation (MRI)
- Torques & attractive forces (MRI)
- Contrast agent toxicity
  - Cardiovascular
  - Allergic
  - Renal
Challenge: Planning Approach

• Targets are often nestled in/between other organs and structures.
• Some access routes are safer
• What path to take?
History of Right Kidney removal for Renal Cell Carcinoma

Abnormal Left Adrenal Gland
Solution: CT Guidance
Solution: Imaging Guidance

- Imaging can reveal normal anatomy & structures along the path of the intervention.
  - Some tissues are less vital
    - Fat
  - Some tissues heal rapidly
    - Liver
  - Some tissues are critical or heal slowly
    - Nerves
Robot to guide device placement

Robot to guide camera & device placement
Challenge 3: How to get safely deep inside the body?
Goal: Fix the heart without damaging it...

- Atrial fibrillation is extremely common, affecting up to 40% of men by age 80 \(^{(1)}\).
- Leads to strokes & embolic events
- Usually caused by abnormal atrial depolarization waves that start near pulmonary vein ostia, rather than the SA node
- Treat by ablating the abnormal circuits

Atrial Fibrillation
Solution: from the inside

- **Access:** Femoral Vein > IVC > RA > LA
- **Ablate a ring of endocardium around each vein ostium to isolate it electrically from the rest of the LA.**
- **How?**
A robot in the heart: TOCCATA study

• Guidance to the heart: x-ray opaque
• Navigation in the heart:
  – EM tracking: creates a 3D map of cardiac interior
  – 3DOF: In/out, Rotation, Flexing
• Electrical contacts to monitor/map impulses
• Contact monitoring: bi-directional contact force haptics with optical interferometry
• Ablation: Delivers RF energy

Map the atrium by touching the walls

- Uses EM tracking
- Avoids radiation
- Point-by-point (means lots of touches)
- Video
“Tacticath”

- Video
Summary

• Blood-filled vessels & chambers provide working room for the robot
• Many functions can be integrated into a small flexible robotic catheter.
• Multiple imaging/mapping modalities can be used together to enable parts of one procedure
  – X-ray fluoroscopy
  – 3D spatial mapping
  – Contact force
  – Electrical mapping
• Procedures *still* take hours...
Case

- 53 y/o with **severe** abdominal pain after eating at Taco Bell
- Presents to his local emergency room
Non-contrast CT scan
Non-contrast CT scan
MRI

- Kidney mass is almost certainly renal cell carcinoma.
- Patients needs an operation to resect it.
Challenge: No room for the Robot

• Most robots only work in an open space
• There are very few naturally occurring “open spaces” in the body:
Solution: Robotic Surgery with insufflation of air/CO2

Solution: Robotic Partial Nephrectomy with insufflation of air/CO2

Where’s is the mass in the kidney?

https://www.youtube.com/watch?v=PMO9zDzZLFU
Intraoperative Ultrasound to confirm

https://www.youtube.com/watch?v=PMO9zDzZLFU
Case summary

• Scans sometimes find important unexpected problems
• Can instill CO₂ to make space for small robotic instruments in some locations, e.g. peritoneum
• Even looking right at the Kidney itself, it may be hard to see the tumor
• Intraoperative US performed via laparoscopic port.
• US still hard to interpret because side-by-side display is not registered to vision
• Don’t eat at Taco Bell?
Fusion of US to Surgeon’s view

What if there is no safe way to make space or find space?

- Consider traversing a non-critical structure that can heal.
- Imaging can guide the devices to the target.
- Miniaturization is critical for avoiding complications.
- Imaging can monitor the effects of the devices in the actual body.
CT - Guided RF & Cryo Ablation
CT - Guided RF & Cryo Ablation
Challenge: What if you really don’t want to physically traverse anything at all?
Prostate Cancer Radiotherapy with Cyberknife
Essential Tremor

Drawing A

Drawing B

Drawing C

PLEASE WRITE IN THE SPACE PROVIDED: "This is a sample of my best handwriting."

This is a sample.

Courtesy Pejman Ghanouni
Benign essential Tremor

- 8-12 Hz oscillations of opposing muscles
- The most common movement disorder (prevalence up to 4%)
- Progressive
- Disabling
- Closed loop hysteresis
- Medical therapy often fails
- Can be treated by surgery of the Ventral Intermediate Nucleus of Thalamus
New Treatment: MRI-guided High Intensity Focused Ultrasound

- Target the VIM nucleus in the Thalamus using MRI (only a few mm in size!)
- Ablate tissue with HIFU
- Entirely non-invasive
Essential Tremor pre & post HIFU

Please write in the space provided: "This is a sample of my best handwriting.

This is a sample of my best handwriting.
Result of VIM HIFU


[video]
Engineering Opportunities

• Better imaging
  – Improved tissue-specific contrast
  – Better guidance
  – Better visualization (presentation of complex image data)

• Better tools
  – Smaller, less invasive
  – More precise, novel mechanisms
  – “Self aware”

• Autonomy?
Deepwater Horizon
4/20/2010

4.9 billion barrels of oil
87 days
A magnetometer was lowered from the surface, which allowed engineers to determine the precise location of the existing well.

The instrument induced a current in the steel casing of the existing well to generate a magnetic field. Another section of the same tool then measured the direction and distance to the existing well.

**INTERCEPTION**
The existing well was intercepted at 17,977 feet, about 800 feet above the reservoir.

A drill bit punched a hole into the annulus, the space between the outside of the well’s casing and the bore hole. After tests indicated that there was no oil and gas at the intersect point, engineers pumped cement into the annulus.
“Holoneedle”

Michael Lin & Jung Hwa Bae, Stanford BDML Lab
Autonomy: SpaceX Thaicom8 Booster Landing

May 27, 2016

14 Story-tall booster
Apogee: ~70 km.
~8000 km/h
Landing:
~600 km down range
Accurate within ~
Thanks