MR Guided Prostate Interventions
Advantages of MRI

- No ionizing radiation
- High soft-tissue contrast
- High resolution imaging
- True 3D volumetric imaging
- Multi-parametric imaging
  - T1/T2 weighting, Functional, Diffusion, Flow, Temperature, Oxygenation, ...
- Can provide “real-time” imaging capabilities
Why MRI?

US

CT

MRI

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Close Bore Magnet
Intra-operative MRI – open magnet in the OR

Operating Room

Black, Jolesz et al., Harvard BWH
MRI-Guided Laser Ablation

Black, Jolesz et al., Harvard BWH
MRI-Guided Laser Ablation

Black, Jolesz et al., Harvard BWH
Transperineal Implants & Biopsy

Tempany et al., Harvard BWH

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Transperineal HDR & Biopsy

Menard et al., NIH
Why is MRI so hard?

DiMaio, Fischer, Fichtinger et al., JHU

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Why is MRI so hard?
Point & Click System Concept

Targeting Parameters

Physician's Interface

Physician

MRI Scanner

Robot

Patient

Real-time Tracking System

Position

Images

MRI Scanner Computer

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger (Johns Hopkins and NIH)
Transrectal Prostate Interventions in 3T MRI

Decoupled 3DOF
1. Translate
2. Rotate
3. Insert needle

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger (Johns Hopkins and NIH)
The End-Effector (First Prototype)

Signal projection for one tracking coil

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger (Johns Hopkins and NIH)
Human Grade Device

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger (Johns Hopkins and NIH)
Human-Grade Device

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger (Johns Hopkins and NIH)
Robot in Clinical Trials

- From concept to 2 trials in 22 months
- ~50 biopsies & marker seed placements
- No severe adverse events
- Supports 4 clinical trials as validation tool

Example

CREDIT: Krieger, Susil, Ménard, Coleman, Singh, Whitcomb, Atalar, Fichtinger (Johns Hopkins and NIH)

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Liquid Injection monitoring

canine studies

GOOD  BAD
Transperineal Brachytherapy / Biopsy

Robot Position

GE 3T Excite bore

robotic needle driver

Patient Position

leg support

patient

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Mechanical Design

Kinematic Structure

Workspace

<table>
<thead>
<tr>
<th>Degree of Freedom</th>
<th>Motion</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Gross Axial Position</td>
<td>1m</td>
<td>Manual with repeatable stop</td>
</tr>
<tr>
<td>2) Vertical Motion</td>
<td>0-100mm</td>
<td>Precise servo control</td>
</tr>
<tr>
<td>3) Elevation Angle</td>
<td>$+15^\circ, -0^\circ$</td>
<td>Precise servo control</td>
</tr>
<tr>
<td>4) Horizontal Motion</td>
<td>$\pm 50$mm</td>
<td>Precise servo control</td>
</tr>
<tr>
<td>5) Azimuth Angle</td>
<td>$\pm 15^\circ$</td>
<td>Precise servo control</td>
</tr>
<tr>
<td>6) Needle Insertion</td>
<td>120mm</td>
<td>Cooperative or Automated</td>
</tr>
<tr>
<td>7) Canula Retraction</td>
<td>60mm</td>
<td>Cooperative or Automated</td>
</tr>
<tr>
<td>8) Needle Rotation</td>
<td>360$^\circ$</td>
<td>Manual or Automated</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Axis</th>
<th>Average Error</th>
<th>Standard Deviation</th>
<th>RMS Error</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-plane (x)</td>
<td>0.017mm</td>
<td>0.026mm</td>
<td>0.031mm$^2$</td>
<td>$N = 100$</td>
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<tr>
<td>Out-of-plane (z)</td>
<td>0.089mm</td>
<td>0.11mm</td>
<td>0.14mm$^2$</td>
<td>$N = 100$</td>
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<tr>
<td>Rotation ($\theta$)</td>
<td>0.28°</td>
<td>0.23°</td>
<td>0.37$^o$²</td>
<td>$N = 90$</td>
</tr>
</tbody>
</table>
Patient workflow & MRI compatibility

No Robot

Prostate

Robot Operational

Robot

Tip

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Other work at Johns Hopkins

Movie1
Movie2
Movie3
Innomedic Robot
Innomedic CAD/CAM workflow

set up on bed                      image                                  plan
move robot                         insert needle manually                 confirm in image
New wide & short bore magnets coming...

Field strength 1.5T – 3T
Bore diameter ~ 75 cm
Isocenter depth ~125 cm