Who are we?

- National Center for Image Guided Therapy (NCIGT)
- Multi-disciplinary research laboratories in Brigham and Women’s Hospital.
- Strong emphasis on real clinical applications of advanced medical robots and medical image processing.
NCIGT and AMIGO

- Advanced multi-modality image guided operating room
- PET/CT, OR, 3T MRI
- NIH- and hospital-funded research-oriented operation theater
- Designed and used by multi-disciplinary clinical teams (including me!)
- Open in mid Dec 2010, First case in Feb 2011

Who am I?

- Pre-doctoral fellowship at BWH in ‘95
- Post-doc, then Junior Faculty at BWH/Harvard Medical School, ’98-’01
- Univ. Tokyo Mech. Engineering faculty ’01-’05
- Back to BWH ’05
  - Technical Director, IGT Program at BWH ’05
  - Founded Surgical Navigation and Robotics Laboratory ’07
  - Leader, Navigation and Robotics Core, NCIGT, ’10
- Continuing research interest in Image Guided Therapy and Medical Robotics

Advanced science and technology in a hospital

Scientists fully funded by competitive research funds
Clinicians partially funded by research funds, and strongly encouraged to establish clinical and scientific research program

My/Our Value

Science

Application

Engineering
Part 1/4
Close-bore MRI-guided biopsy

Boston City View from Charles River

MRI-guided prostate biopsy

- Prostate cancer
- Alternative to TRUS guided biopsy after repeated negative biopsy with rising PSA level [D’Amico 2001]
- MRI for imaging, planning, target localization, guidance
- Challenge
  - Use of contemporary wide-bore 3T MRI scanner, and pre-operative diagnostic MRI

Hata et al. Interventional MRI 2010

Engineering methods in IGT
MRI-guided prostate biopsy

- Pre-operative imaging fusion
- DCE MRI analysis

Planning

Monitoring/Control

- Target definition
- Intra-operative image feedback

Guidance

- Tracker support
- Patient-to-image registration
- "Navigation"

Pharmaco-kinetic analysis of dynamic contrast enhanced images

- Tempany, Tuncali, Tokuda, Hata (BWH), and Iordachita (JHU)

Role of Slicer in IGT research

- Pre-operative imaging fusion
- DCE MRI analysis
- Neuro-fiber tracking

Planning

Monitoring/Control

- Target definition
- Intra-operative image feedback

Guidance

- Tracker support
- Patient-to-image registration
- "Navigation"

Building apparatus

- Tokuda, Hata, Tempany, Tatli, et al
Deformable Registration of Pre- and Intra-procedural Images

BrainsFit Module in 3D Slicer
Rigid, Affine, B-spline deformable registration
Federov et al, ISMRM 2011

MRI-guided biopsy at 3T

Biopsy Targets

Tempany et al
Role of Slicer in IGT research

- Pre-operative imaging fusion
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Planning

Monitoring/Control

- Target definition
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Guidance

- Target definition
- Intra-operative image feedback

Integrated needle guidance template and z-frame

Z-frame calibration

Method to register the template to the MRI

MRI scan → Registration MRI vs. design model → Template and MRI registered

DiMaio et al
Biopsy under MRI guidance

Accuracy assessment

Part 2/4
MRI-guided robotic surgery

Harvard Medical School
**Guidance by robot**

- Pre-operative imaging fusion
- DCE MRI analysis
- Neuro-fiber tracking

**Planning**

- Target definition
- Intra-operative image feedback

**Monitoring/Control**

- Tracker support
- Patient-to-image registration
- "Navigation"

**Robot**

**Medical Robotics**

[Taylor, Stoianovici 2003]

- Surgical assistance
  - To enhance the ability of human surgeons to perform surgical procedures
  - Product-level developments by Intuitive and Hanson Medical, etc

- Surgical CAD/CAM
  - A computer model of a patient from medical images
  - Plan an intervention, registering the computer model/plan to the actual patient
  - Using robots to help carry out the plan
  - [BWH contribution] Use intra-operative images to update medical images and plans
  - [BWH contribution] Use intra-operative images to control robots

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**Innomotion**

- [Gutmann, 2002], [Meizer, IEEE EMBS Magazine 2008]
- The MR-compatible, servo-pneumatically driven, robotic device
  - Highly redundant safety features meeting EU standard
  - Custom made actuators and sensors
- Percutaneous biopsies
  - [Moche et al., JMRI, 2010]
  - Femur and sacral bone, lesser pelvis, iliac lymph node, lumbar spine abscess, liver
  - 1.0T

**ROBITOM, University of Jena**

- Kaiser Fischer et al 2000
- Pfleiderer et al 2008
- Breast biopsy
- 1.5T scanner
- 14 cases tested
MRI Robot

- Designed for 0.5T open scanner
- Synergistic control
  - Needle holder controlled manually
  - Robot keeps the selected target at the remote-center-of-motion
  - [Hata et al JMRI 2008]
- Clinical feasibility study
  - [Morikawa Am J Surg. 2009]

Utrecht Prostate Robot

- 1.5T
- van den Bosch 2010
- Deliver fiducial gold markers inside prostates eligible for external beam radiotherapy treatment (EBRT)

"The robot tapped the needle stepwise towards this position while controlling the step size (typically 5 mm) and the needle depth."
"During the tapping fast 2D MR scans were acquired to track the needle trajectory on-line and to independently monitor the needle depth."
**Balanced steady state free precession**

- Bladder
- Prostate
- Nucleus

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**JHU/BWH 3T Robot**

- Scanner independent
  - Tested in GE 3T, Siemens 3T wide bore
- Prostate Intervention
- Pneumatic motor
- Integrated scanner and robot control

*Fischer, Tempany, Iordachita*

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**Leveraging software from established clinical methods**

- P01 Robotics core, Hata
Part 3/4
Vision: Image-driven robots

Harvard College

Organ motion

Motion Compensation

Ishikawa, Univ. Tokyo

Motion Compensation

Swimming Endoscope

Spermatozoa Swimming from the Lugworm Arenicola marina

MRI swimming robot

2cm swimming tail, in 3T MRI
Kosa Hata et al. IEEE ICRA 2010
Imaging for Navigation and Marking

B0 field for propulsion

Imaging for capsule localization

MRI capsule endoscope

Research Impact

Dissemination

Industry Collaboration

NA-MIC Programming Week
What is 3D Slicer?

- 3D Slicer is...
  - Free, Open-software
  - An end-user application for 3D medical image computing research and Image Guided Therapy
  - A platform for research
  - A freely-downloadable program with source and binaries for Windows, Linux, Mac OSX

Software Design

- To maximize function commonalities among applications
  - Brain (biopsy, craniotomy, NdYAG laser ablation)
  - Prostate (brachytherapy, biopsy)
  - Liver and kidney (Microwave, Cryo, laser ablation)
  - Endoscopy (broncho-, neuro-, feto-scopy)
Objective: Develop and integrate end-to-end application module inside 3D Slicer to perform robotic prostate biopsy intervention


Interfacing commercial navigation to Slicer

- BrainLab
  - Commercial navigation
  - Everyday use, stable
- 3D Slicer
  - Science/innovation

Feasibility study of innovative scientific method with minimum disruption to clinical workflow
Realtime Fiducial Seeding

Intra-operative Real-time Querying of White Matter Tracts During Frameless Stereotactic Navigation


Video Supplement

Integration to MRI scanners

Nagoya Institute of Tech
Conclusion

- Image Guided Therapy
- Intra-operative Image Guided Therapy
- Robots as guidance tool
- Added value of robots in image-guided therapy
  - Needle detection
  - Motion compensation
- This presentation is posted at wiki.na-mic.org
- Visit the following sites for the material and the papers related to this talk
  - www.snrlab.org
  - www.ncigt.org
  - www.slicer.org
  - www.na-mic.org

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