Tutorial: Image Guided Therapy

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Learning objective

• To understand the fundamentals of medical imaging
• To understand the role of medical imaging to guide therapy and diagnosis – Image Guided Therapy
• To learn role of robotics in Image Guided Therapy research and key enabling technologies
Imaging in medicine

• We are in a perfect city to discuss medical imaging.
The Nobel Prize in Physics 1901

Wilhelm Conrad Röntgen

X-ray

X-ray Fluoroscope
The Nobel Prize in Physiology or Medicine 1979

Cormack

Hounsfield

EMI CT Scanner
London Science museum
Slicer Demonstration of CT

Toshiba
The Nobel Prize in Physiology or Medicine 2003

Lauterber

Mansfield

Mapping of Nuclear magnetic resonance (NMR): quantum mechanical magnetic properties of the hydrogen atoms in water and fat
Slicer Demonstration of MRI
Japan Prize 1991

Wild

Philips
Image Guided Therapy

Philips
Liver Cancer

Unresectable liver cancers (some T1 to T4, N0, M0 tumors)
The tumor is too large to be removed safely
The tumor is in a part of the liver that makes it hard to remove (such as very close to a large blood vessel)
There are several tumors or the cancer has spread throughout the liver
Image Guided Therapy Example...

Ablative therapy

• Suitable for unresectable liver cancers
• Heat and cooling energy to destroy cancerous tissue
• Less invasive than open surgery
• Image guidance is crucial for [QUIZ]
Role of Imaging for Therapy

- Targeting
- Navigation and Guidance
- Monitoring

Song, Tuncali
Image Guided Therapy
Roentgen

- Nov. 8, 1895: found X-ray
- Dec. 28: paper submitted
- Jan. 5: paper published
- Jan 13: First diagnostic imaging
- Jan 14: First image-guided therapy (needle removal)
Problem statement

- Precise and controlled placement of ablative probes mandatory
  - To maximize the treatment effect
  - Minimize damage to surrounding critical structures
- Free hand approach limit physicians’ precision placement of ablation tools.
Needle positioning device on a surface coil for MRg liver interventions

With Conor Walsh (Harvard) and Kemal Tuncali (BWH)

Wu, Torabi, Walsh (MIT/Harvard), Tuncali, Yamada, Hata (BWH), Fischer (WPI), NCIGT WS poster
3D Slicer
Canon Robots for abdominal interventions

- Patient-attached, RCM at skin entry
- Can accommodate an imaging coil
- Fiducial marker based registration
Prostate Cancer

• In the US, 220,000 men are diagnosed with Prostate cancer.
• 80% of prostate cancer patients have localized cancer, Stage I, cancer.
• Prostate cancer is slow glowing disease.
• 5 year survival rate of localized prostate cancer is 100%.

SEER 18 2006-2012, All Races, Males by SEER Summary Stage 2000
Treatment options for localized Stage I prostate cancer

• Watchful waiting.
• Active surveillance. If the cancer begins to grow, hormone therapy may be given.
• Radical prostatectomy, usually with pelvic lymphadenectomy. External-beam radiation therapy.
• Internal radiation therapy with radioactive seeds.

Biopsy is crucial part of staging and making treatment decisions
Today’s Standard Transrectal Ultrasound Prostate Biopsy Misses 25% of Significant Cancers

• Standard Transrectal Ultrasound biopsy procedure is inadequate because:
  – 6-12 locations are “blindly” sampled
  – High incidence of false negative results drives 31% repeat rate
  – Can cause serious complications
  – Low detection of tumors in prostate apex

AUA
MRI and MRI-guided biopsies

• MRI of prostate can detect clinically significant cancers [Barentsz 12]
• MRI localizes prostate cancers better than digital exam and blind biopsy [Mullerard 05]
• Why not use MRI for guiding biopsy?
Prostate Intervention Tools

(A) Base board
(B) Leg support
(C) Stationary frame
(D) Template (plexiglas)
(E) “Z-frame”
Tempany, Song, Tokuda, Kacher, Iordachita, Fairhurst, Kanan, Tuncali
Tempany, Fennessy, Tuncali
Smart Template

Song, Tokuda, Tuncali, Tempany
Smart Template Design

Ultrasonic Motors

Biopsy Gun

Crossbar Needle Hole

Limiter Sensors

Timing Belts

Z-frame attached

Inside view
Teleoperation to Control Robotic Insertion

Greg Fischer, WPI
ROBITOM, University of Jena

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

Pfleiderer et al 2008
Utrecht Prostate Robot

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

• “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”
Questions?
Fundamentals of Robotics in IGT
Design consideration

- Disease and anatomy
- Procedure (approach, medical tools, anesthesia)
- Metric for clinical success
- Participants in the procedure
- Workflow
- Devices involved
Technical Components

Targeting

Navigation and Control

Monitoring
Roles of robotics can be best described using space technology as analogy.
Guidance, Navigation and Control

Charles Stark Draper and MIT Draper Labs (1969)
Technical Components

Targeting

Navigation and Control

Monitoring
Enabling engineering methods in Image Guided Therapy

- Imaging
- Graphics
- Control

- Tracking/Guidance/Navigation in action (demonstration)
- Image processing (demonstration)
- Vision -> motion compensation and detection
- Registration
  - Registering a device to images
Slicer IGT Demonstration
Image Processing
Deformable Registration of Pre- and Intra-procedural Images

BrainsFit Module in 3D Slicer
Rigid, Affine, B-spline deformable registration
Federov et al, ISMRM 2011
Vision- Image-based Motion Adaptive Instrument

Hong J, Hata N, et.al., *Phys Med Biol*, 49(3), 441-455, 2004
Tool to image registration

- Mandatory to use devices and robots in IGT
- To register the template guide’s coordinate system to images
- Often disruptive to clinical workflows
Design consideration

- Disease and anatomy
- Procedure (approach, medical tools, anesthesia)
- Metric for clinical success
- Participants in the procedure
- Workflow
- Devices involved
DiMaio et al.

MRI scan

Registration MRI vs. design model

Template and MRI registered

DiMaio et al.
Registration for abdominal robot
Image Guided Therapy Market Segments: Not Independent Silos, the Boundaries are Blurring...

- Image Guided Surgery: $1.4 Billion
- Robotics Assisted Surgery: $2.6 Billion
- Robotic Radio Surgery: $560 Million

Frost & Sullivan 2014 Estimates for U.S., Western Europe, and Asia
Image Guided Therapies are Growing > Twice as Fast as Medical Imaging Market

Market: U.S., Western Europe, and Asia (excluding China and India)
Source: Frost & Sullivan
Monteris
Visualase MRI-guided laser ablation of brain tumor and epilepsy

Copyright Harmonus
• 1999-2007
  – SBIR grant from the NIH
  – Over $7.2M in NIH and state grant funding
  – $9.4M in private investments
• 2006
  – First in man study
• 2007
  – The device received FDA 510(k) clearance for neurosurgery
  – then general surgery and urology
• 2014
  – the company was acquired by Medtronic for up to $105M
Conclusion - Image Guided Therapy

• Provides significant benefits for healthcare systems and patients
  – reduced patient trauma
  – shorter recovery times and hospital stays
  – lower costs from fewer medical errors and complications.

• Improves accuracy and efficiency of complex surgical procedures
Real-time intraoperative imaging

• Captures changes in patient anatomy
  • not apparent through pre-operative imaging
• With Robotics, enables physicians to create exact detailed surgical plan
  • the best incision site, the optimal path to the targeted area, and what critical structures must be avoided
• Converts open surgery to minimally invasive procedures
  • offering new alternatives for patients who would have been considered inoperable in the past