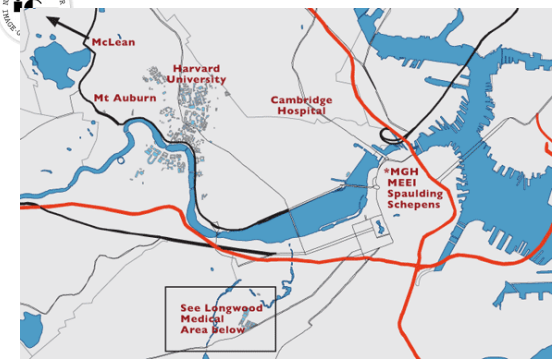
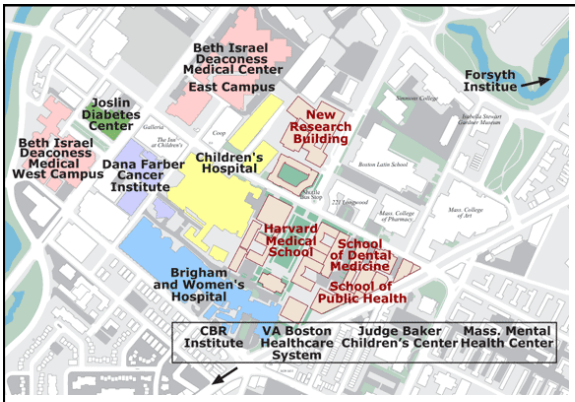
National Center for Image Guided Therapy
Brigham and Women's Hospital
Boston, Massachusetts USA

a teaching affiliate of
Harvard Medical School

Role of Image Processing, Navigation and Robots in Image-guided Intervention

Nobuhiko Hata
Associate Professor of Radiology
Harvard Medical School





Who are we?

- Multi-disciplinary research laboratory in Brigham and Women's Hospital.
- Part of National Resource Center for Image Guided Therapy.
- Strong emphasis on real clinical applications of advanced medical robots and medical image processing

Physicians in Engineering Lab (in a hospital)

Engineers in OR

Our value

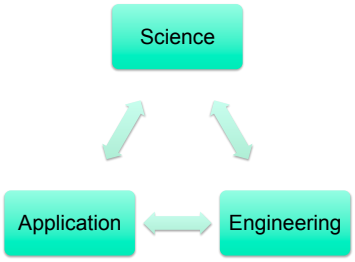
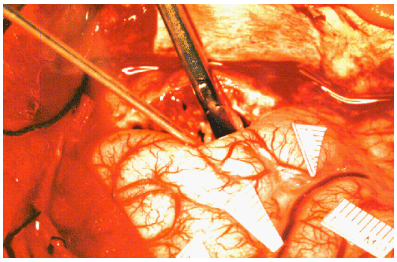
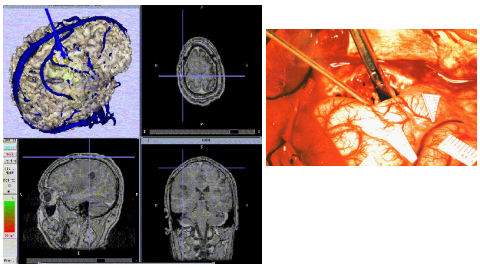


Image Guided Therapy



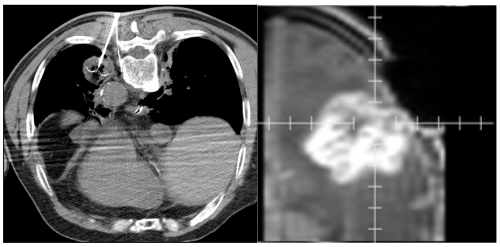
Where are we? What should we do?

Intra-operative Image Guided Therapy



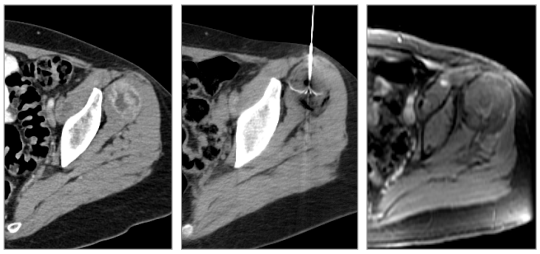
Slide courtesy of Drs. Jolesz and Elhawary

INTRA-OPERATIVE image guidance



PLAN – TX - ASSESS

CT-GUIDED RFA IN SOFT TISSUE



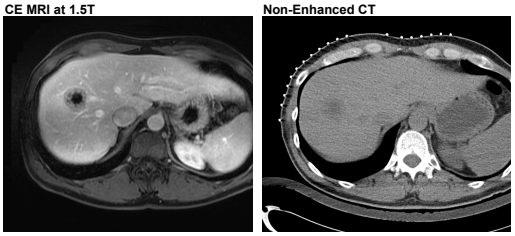
CE CT PRE | CT INTRA | CE MRI POST

Silverman et al

CLINICAL NEED – Example 1

Pre-Procedure
CE MRI at 1.5T

Intra-Procedure
Non-Enhanced CT



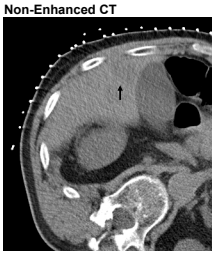
Recent BWH ablation case: Pre-Proc MRI vs Intra-CT
47yo M, 3cm liver metastasis of sq cell ca in Seg 8; lung & vessels nearby

Silverman et al

CLINICAL NEED – Example 2

Pre-Procedure
CE MRI at 1.5T

Intra-Procedure
Non-Enhanced CT



Recent BWH Ablation Case: PreProc MRI vs Intra-CT
69yo M, 7cm liver metastasis of colon cancer; look for coverage; GB & colon nearby

Dx comes from one imaging modality … Tx takes place under another.

SOLUTION: REGISTRATION

Bring Pre-procedural diagnostic MRI into the Intra-procedural interventional space

PRE-PROCEDURAL CE MRI

Example:
Registered Data

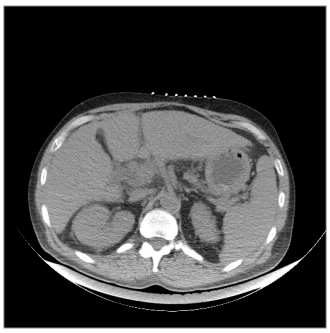
--MRI Pre

BWH Ablation Case
50yo M, 2cm primary liver tumor (HCC) in segment 2

INTRA-PROCEDURAL CT

Example:
Registered Data

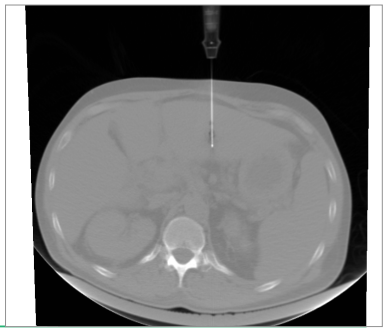
--CT Intra



RFA ELECTRODE PLACED

Example:
Registered Data

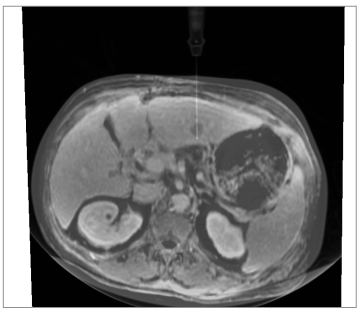
--CT Intra

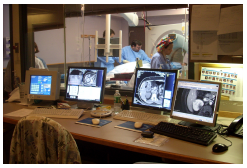


REGISTERED IMAGES

Example:
Registered Data

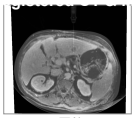
--Merged MRI & CT





Intra-Proc CT

Pre-Proc MRI



Elhawary, Oguro

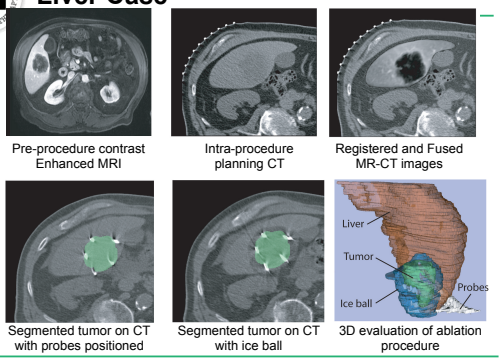
Registration Method in 3D Slicer

Non Rigid Registration Method

- Global motion of the liver modeled with Affine Registration
- B-Spline interpolation model for local deformation of the tissue
- Capable of registration between multiple modalities (MR – CT, CT – CT)
- Requires manual segmentation of the organ for higher accuracy
- Applied to liver and kidney

Elhawary, Oguro

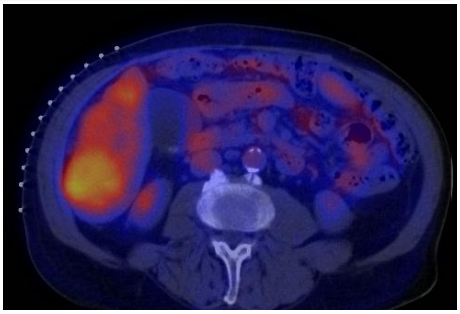
Liver Case



Pre-procedure contrast Enhanced MRI | Intra-procedure planning CT | Registered and Fused MR-CT images

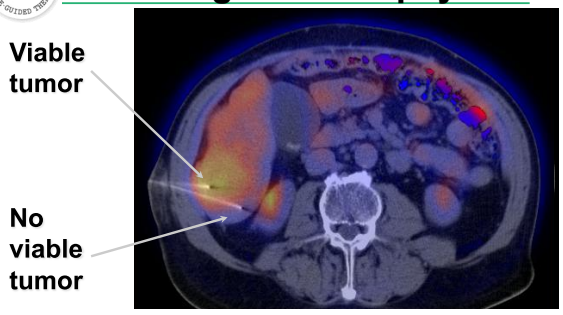
Segmented tumor on CT with probes positioned | Segmented tumor on CT with ice ball | 3D evaluation of ablation procedure

PET/CT-guided Biopsy



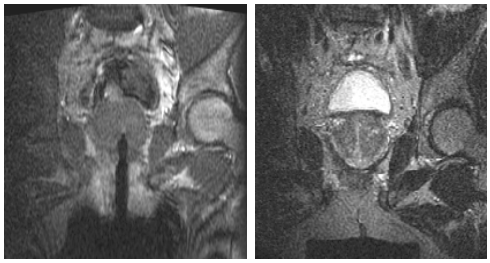
MIPAV – Medical Image Processing and Visualization (MIPAV) software – NIH
McAuliffe et al IEEE Proceedings 2001

PET/CT-guided Biopsy



MIPAV – Medical Image Processing and Visualization (MIPAV) software – NIH
McAuliffe et al IEEE Proceedings 2001

MR-guided Prostate Biopsy

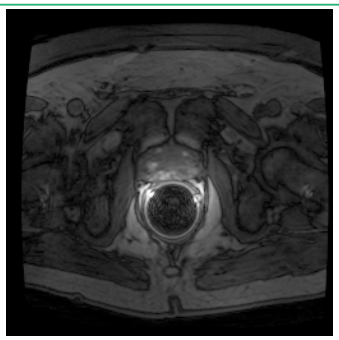


Intra-procedural 0.5T FGR for needle control

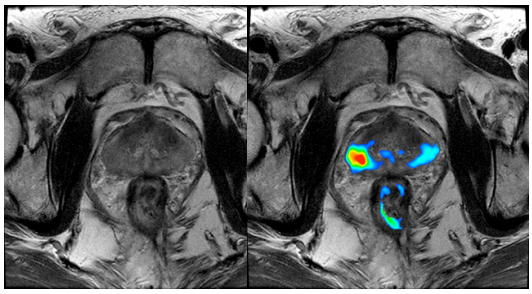
Registered Pre-procedural 0.5T T2w

Hata N et al, Radiology. 2001;220(1):263-8.

Diffusion Contrast Enhanced MRI

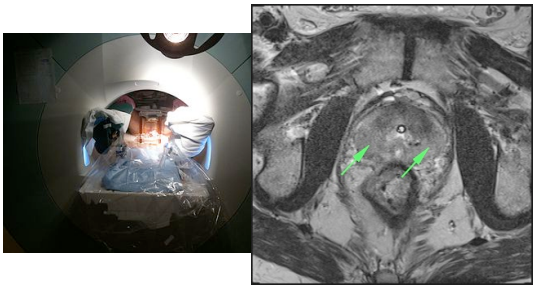


3T Pre-procedural MRI



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

MRI-guided biopsy at 3T



Fun time!

SLICER DEMONSTRATION

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

Elhawary H., Norton I., Liu H., Patel P., Rigolo L., Papademetris X., Hata N., Golby AJ

Video Supplement

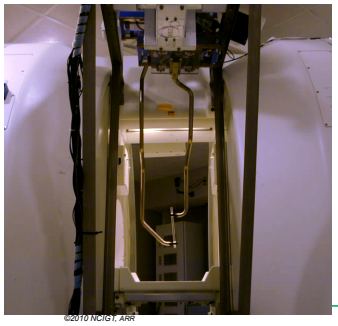
Medical Robotics
[Taylor, Stoianovici 2003]

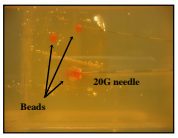
- Surgical assistance
  - To enhance the ability of human surgeons to perform surgical procedures
  - Product-level developments by Intuitive and Hanson Medical, etc
- Surgical CAD/CAM
  - A computer model of a patient from medical images
  - Plan an intervention, registering the computer model/ plan 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

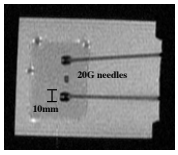
BWH 1st Generation
MRI robot for prostate intervention

- Issue
  - Prostate needle placement up to 6 mm inaccuracy
  - fixed needle guide template with holes spaced at least 5mm apart
  - limits needle trajectory position and orientation
- Rationale
  - Robot as dynamic needle guide for accurate needle placement [Chinizei MICCAI 1999]

DiMaio SPRobot-assisted needle placement in open MRI: system architecture, integration and validation. Comput Aided Surg. 2007;12(1):15-24.

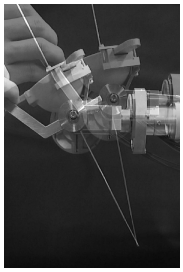


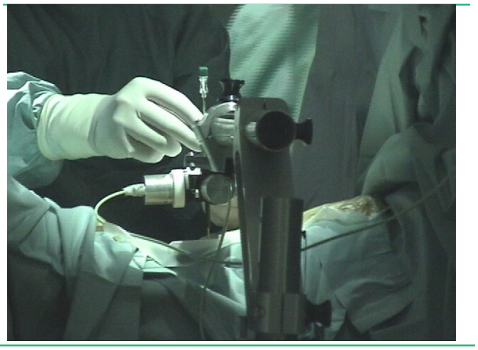




2nd Generation
MRI robot for open-bore scanner

- Needle guiding robot [Hata et al. ICRA 2005] [Hata et al. JMRI 2008]
- Issue: Precision needle placement in MRIg liver tumor ablation
- Solution: Interactive Remote-center-of-motion
- August 2007: First clinical case in liver ablation therapy





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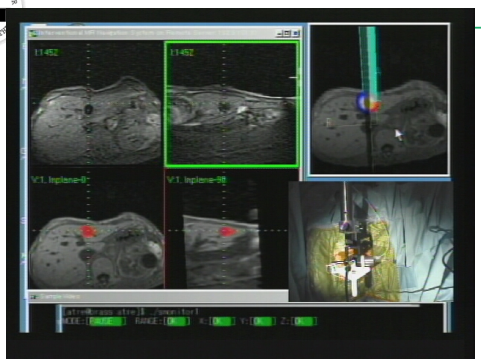

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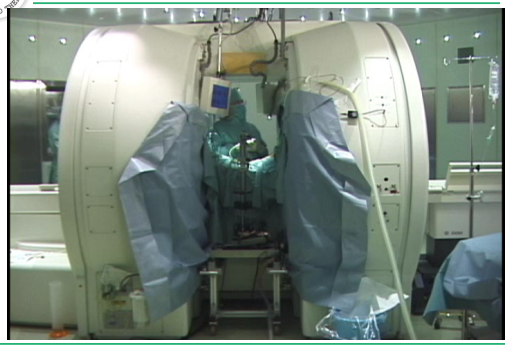

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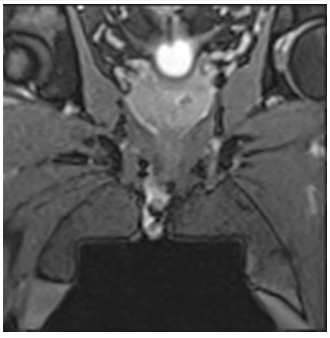
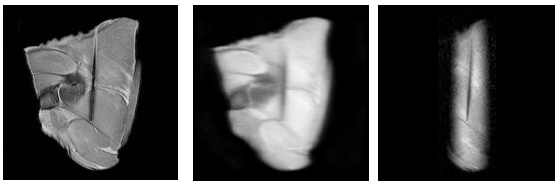


Slide 40

Unmet needs in MRIg prostate intervention

- Ability to detect needle (artifact) to
  - Subscribe scanning plane to follow needle. Particularly to scan image plane perpendicular to needle at its tip.
  - Servo control robotic needle driver [Fischer 2008]
- Added value
  - potential to capture and compensate needle deflection [Blumebfeld 2007]

Rationale for rFOV



TE=60ms, TR=1000ms
12 sec

TE=33.3ms, TR=1665ms
1.6 sec

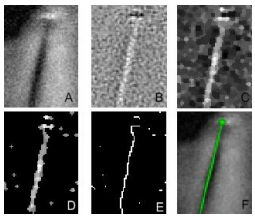
TE=147ms, TR=628ms
pfov=0.33 0.6 sec

B0 perpendicular to needle

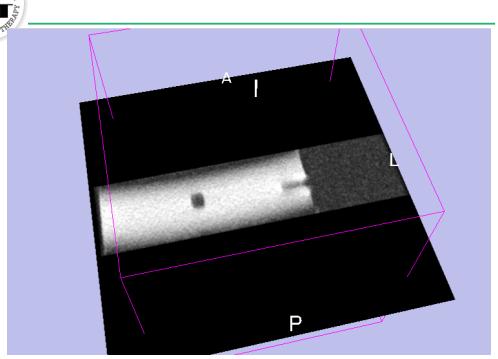
Needle detection

Image-processing software implemented using open-source C++ class libraries VTK and ITK.

1. Laplacian Of Gaussian Filter (A)
2. Dilation and Erosion (B and C)
3. Thresholding (D)
4. Binary thinning (E)
5. Hough transform (F)
6. Find peak intensity change



Experimental Setup



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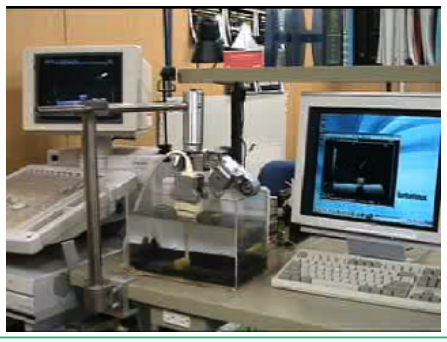
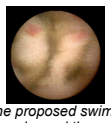


Slide 46

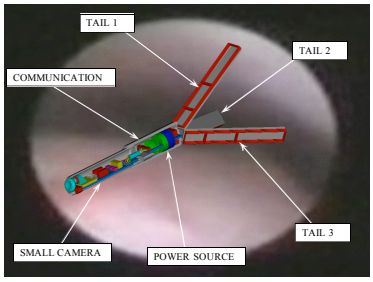
Actively swimming capsule endoscope using MRI for energy delivery, imaging, and navigation

- The capsule endoscope today is purely diagnostic
  - Cannot be used to take biopsies, apply therapy, or mark abnormalities for surgery.
  - Cannot be controlled once it has been ingested
  - Once it has passed a suspicious abnormality, its progress cannot be slowed to better visualize the area




- *The proposed swimming capsule*: A patient may swallow the capsule, and the gastroenterologist maneuvers it using MRI along with guidance and monitoring mapping

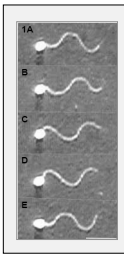
Slide 47



Slide 48

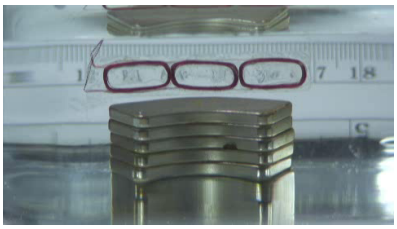
Background

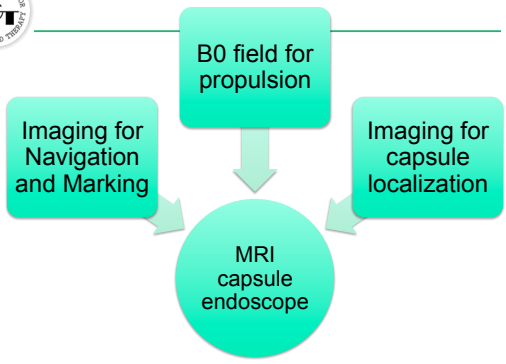
- Flagellar movement of microorganisms in low Reynolds number hydrodynamic field [Colgate et al)
- the oscillating beam can create approximated sinusoidal traveling wave in viscous flow and produces propulsion force effectively (Kosa et al)



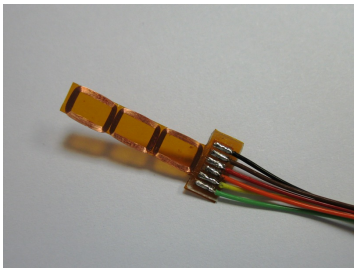
Spermatozoa Swimming from the Lugworm Arenicola marina A. A. PACEY, J. C. COSSON AND M. G. BENTLEY (1994).

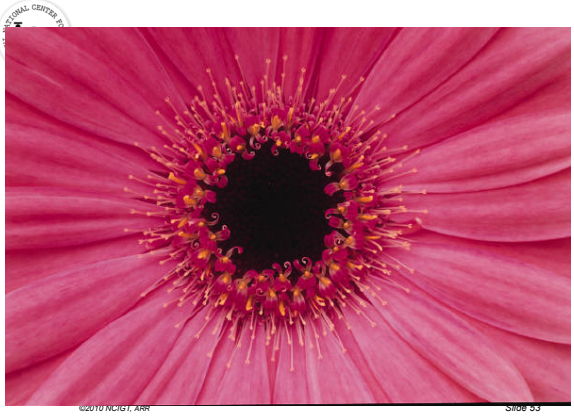
Colgate, J.E. and Lynch, K.M., IEEE Journal of Oceanic Engineering 29, (2004) 660-673.
Kósa, G., Shoham, M. and Zaaroor M., IEEE Conference on Robotics and Automation (ICRA05), (2005) 1339-1343





Prototype





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