Multimodality Image-Guided Surgery & Interventions: 
Multimodality for the Rest of Us

Raj Shekhar, PhD  
Sheikh Zayed Institute for Pediatric Surgical Innovation  
Children’s National Health System  
rshekhar@childrensnational.org

Emerging Multimodality IGIs

1. Multimodality laparoscopic surgery  
   — enabled by external tracking
2. Multimodality interventional radiology procedures  
   — enabled by algorithmic image registration
3. Streamlined arthrography  
   — enabled by robotics
Laparoscopic Surgery

Intra-operative modality: Laparoscopic video
Limitations: Constricted views, internal structures not visualized

Multimodality Laparoscopic Surgery with Ultrasound Overlay

Imaging Systems

Visionsense Laparoscopic Vision System
3D HD Vision
Small (5 mm) scope

BK Medical Ultrasound
Laparoscopic transducers
Standard size (10 mm)
Tracking Systems

• Optical
  – Line of sight
  – Highly accurate
  – Large field of view

• Electromagnetic (EM)
  – No line of sight
  – Less accurate
  – Smaller volume
  – But fine for clinical needs

Abi-Janudheh et al., Cardiovasc Intervent Radiol (2012)

Optical Tracking-Based


EM Tracking-Based
Calibration

- **Laparoscope calibration**: project 3D points in the optical marker coordinate system to the video image
  - **Camera calibration**: OpenCV, Perceive3D single image calibration
  - **Hand-eye calibration**: OpenCV

- **Ultrasound calibration**: transform between the ultrasound image and the optical marker coordinate systems
  - PLUS package

OR Demonstration

Multimodality Laparoscopic Cholecystectomy
(Gallbladder removal surgery)
**Multimodality Laparoscopic Pancreatic Surgery**

![Multimodality Laparoscopic Pancreatic Surgery Image]

**EM Tracking-based Multimodality Laparoscopic Surgery**

![EM Tracking-based Multimodality Laparoscopic Surgery Image]

**Registration Accuracy - Target Registration Error (TRE)**

- Ground truth target: intersection of cross-wire phantom
- Triangulation of two views of the target point
- $2.76 \pm 0.68 \text{ mm (Optical)}$
- $2.43 \pm 0.48 \text{ mm (EM)}$
Run-time Quality Assurance

Anticipated Benefits: Safer surgeries, improved outcomes

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Percutaneous Interventions (Biopsies/Ablations)

Intra-procedural modality: CT/Fluoro or ultrasound

Limitations of CT/Fluoro:
Many targets are CT/Fluoro occult (1/3rd in the liver)
Active lesion may not be visualized

Where do you ablate?

Pre-procedural MR, Intraprocedural CT

Multimodality removes "uncertainty"

Where do you biopsy?

Preprocedural MR, Intraprocedural CT

Multimodality shows heterogenous lesion and needle
Nonrigid Registration through Image Subdivision

- Register subdivisions locally using rigid/affine model
- Locally rigid/affine, globally nonrigid
- Fewer DOF (+): Fewer samples to compute similarity function

Algorithm & GPU Mapping

Multimodality Interventional Radiology Suite
IGT Station enhances but does not change existing IR workflow

Diagnostic MRI  
3D CT  
Needle Movement  
CT Fluoro (2D)  
Needle Movement  
CT Fluoro (2D)  
Automatic Registration with IGT Station

But how do we know these registrations are accurate?

Diagnostic MRI  
3D CT  
Needle Movement  
CT Fluoro (2D)  
Needle Movement  
CT Fluoro (2D)  
Automatic Registration with IGT Station

Validation of Nonrigid Registration

- 3 Experts
- 4 Landmarks
- 18 Image Pairs

<table>
<thead>
<tr>
<th>Inter-observer variability (mm)</th>
<th>(E1, E2, E3)</th>
<th>(Algo, E2, E3)</th>
<th>(E1, Algo, E3)</th>
<th>(E1, E2, Algo)</th>
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</thead>
<tbody>
<tr>
<td>6.2 (5.6-6.9)</td>
<td>6.5</td>
<td>6.4</td>
<td>6.6</td>
<td></td>
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</tbody>
</table>

Algorithm comparable to a typical expert!

Lei et al., J of Digital Imaging, 2009
Validation of Nonrigid Registration

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<tr>
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<th>Slicer (B-Spline) Registration</th>
<th>GPU Registration</th>
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<tbody>
<tr>
<td>Dice (%)</td>
<td>89.3</td>
<td>88.3</td>
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<tr>
<td>95% Hausdorff (mm)</td>
<td>11.4</td>
<td>13.1</td>
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<tr>
<td>Time (s)</td>
<td>557.1</td>
<td>87.6</td>
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Tokuda et al., Acad Radiol, 2015

Real-Time Quantitative Quality Assessment: GPU Accelerated Autonomous Metrics

Plishker et al., Conf Interventional Onc, 2016

Anticipated Benefits of Multimodality IR

- Faster time to target, with less radiation
- Adequate biopsy yields
- Optimal ablation zone coverage
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Arthrography

- Patient with dislocated shoulder, referred for arthrography
- 2-Step process: Fluoroscopic injection, followed by MRI
- Arthroscopic repair of injury
- If shoulder injection could have been done in MRI
  - Workflow would be streamlined
  - Fluoroscopy dose eliminated

MRI Access Can Be Difficult

- Patient access in a closed-bore MR magnet is awkward
- Not ergonomic for the interventional radiologist
Robotically Assisted MRI-Guided Arthrography

MRI Compatible Robot

- Body mounted robot for needle positioning in a closed-bore magnet
- MRI compatible
  - Plastic parts made by rapid prototyping
  - Piezoelectric motors
  - Compatible encoders
- Four degrees of freedom
  - Two for needle tip (T1, R1)
  - Two for needle orientation (R2, R3)
- Accuracy: 2.95 ± 2.04 mm

ArthroBot Demonstration
Conclusions

• Multimodality IGIs add a new level of sophistication
• Ways to achieve multimodality
  – Tracking
  – Registration algorithms
  – Robotics

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