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

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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

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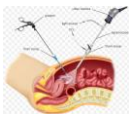
Laparoscopic Surgery


Operating Room


Sagittal View


Laparoscopic View

Intra-operative modality: Laparoscopic video

Limitations: Constricted views, internal structures not visualized

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Multimodality Laparoscopic Surgery with Ultrasound Overlay


Laparoscopic video


Ultrasound


Fusion image

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Imaging Systems


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


BK Medical Ultrasound
Laparoscopic transducers
Standard size (10 mm)

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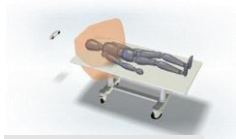
Tracking Systems

- 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



7/38 Abi-Jaoudeh et al., Cardiovasc Intervent Radiol (2012)

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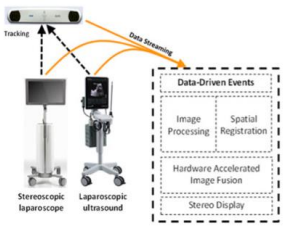
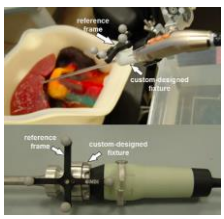
Optical Tracking-Based





8/38 Kang et al., Surg Endosc. 2014

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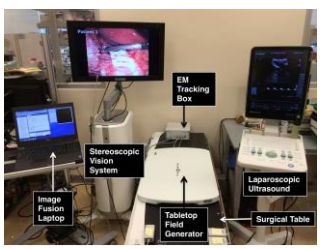
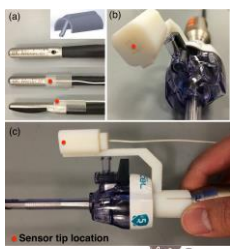
EM Tracking-Based





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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

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OR Demonstration

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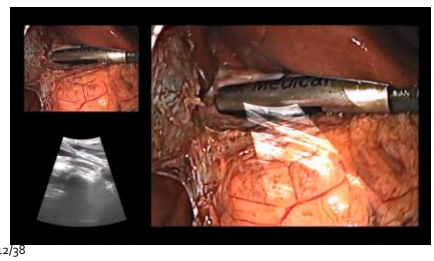
Multimodality Laparoscopic Cholecystectomy (Gallbladder removal surgery)



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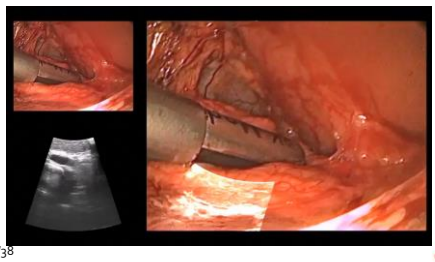
Multimodality Laparoscopic Pancreatic Surgery



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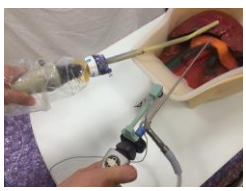
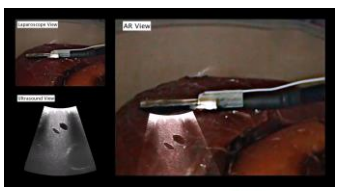
EM Tracking-based Multimodality Laparoscopic Surgery





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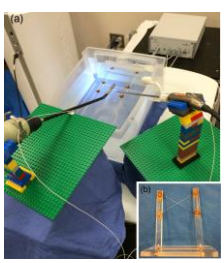
Registration Accuracy - Target Registration Error (TRE)



- Ground truth target: intersection of cross-wire phantom
- Triangulation of two views of the target point
- 2.76 ± 0.68 mm (Optical)
- 2.43 ± 0.48 mm (EM)

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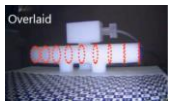
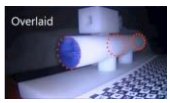
Run-time Quality Assurance





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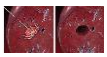
Anticipated Benefits: Safer surgeries, improved outcomes

Bile duct injuries during lap cholecystectomy (4.5K injuries/year)

Suboptimal tumor margins during partial organ resection (70K kidney, 12K distal pancreas)



30% Incomplete & misdirected RF/cryo/microwave ablations

Difficulty localizing lung nodules in video-assisted thoracic surgery (VATS)

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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

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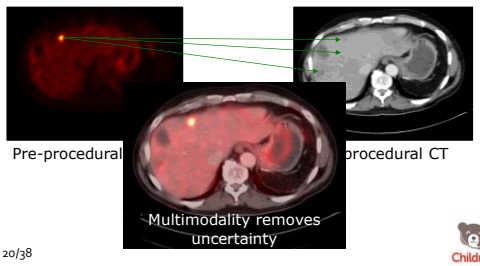
Where do you ablate?



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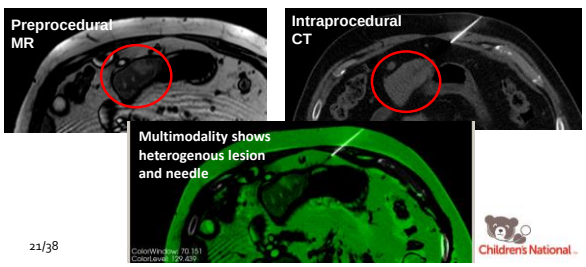
Where do you biopsy?



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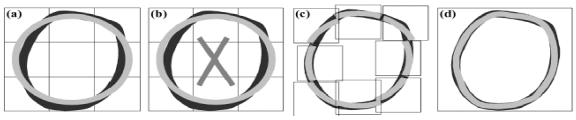
Nonrigid Registration through Image Subdivision



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

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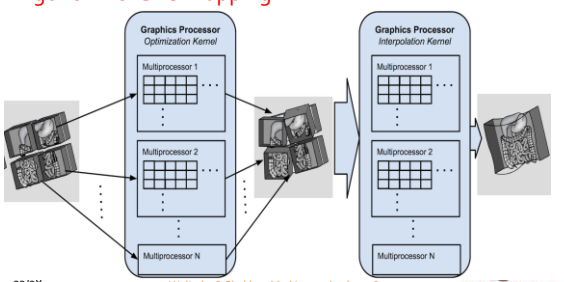
Algorithm & GPU Mapping



Walimbe & Shekhar. Med Image Anal. 2006

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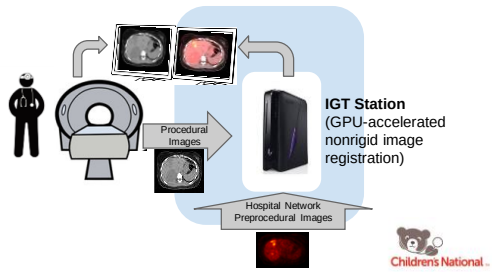
Multimodality Interventional Radiology Suite



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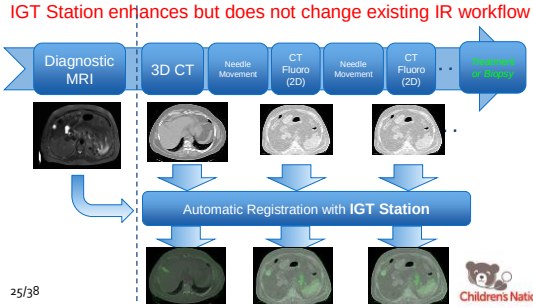
IGT Station enhances but does not change existing IR workflow



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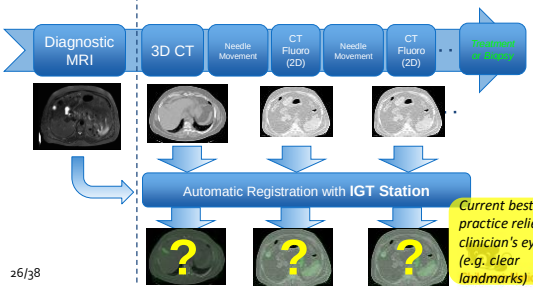
But how do we know these registrations are accurate?



Current best practice relies on clinician's eye (e.g. clear landmarks)

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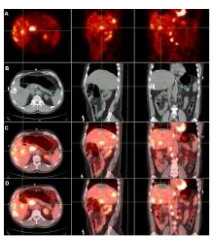
Validation of Nonrigid Registration



- 3 Experts
- 4 Landmarks
- 18 Image Pairs

Inter-observer variability (mm)			
(E1, E2, E3)	(Algo, E2, E3)	(E1, Algo, E3)	(E1, E2, Algo)
6.2 (5.6-6.9)	6.5	6.4	6.6

Algorithm comparable to a typical expert!

Lei et al., J of Digital Imaging, 2009

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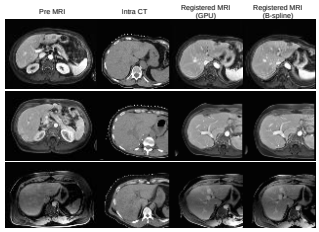
Validation of Nonrigid Registration



	Slicer (B-Spline) Registration	GPU Registration
Dice (%)	89.3	88.3
95% Hausdorff (mm)	11.4	13.1
Time (s)	557.1	87.6

Tokuda et al., Acad Radiol, 2015

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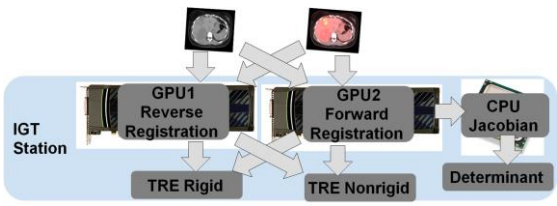
Real-Time Quantitative Quality Assessment: GPU Accelerated Autonomous Metrics



Plishker et al., Conf Interventional Onc, 2016

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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 been done in MRI
  - Workflow would be streamlined
  - Fluoroscopy dose eliminated

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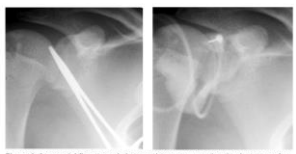

Figure 1. Sequential fluoroscopic images demonstrate a planning image used to mark the patient's skin (left) and subsequent needle positioning with intra-articular contrast (right).

Figure 2. Axial T1 fat saturated images demonstrate a Hill Sachs lesion of the humeral head (left: yellow arrow) and a Bankart injury of the glenoid labrum (right: red arrow).

MRI Access Can Be Difficult

- Patient access in a closed-bore MR magnet is awkward
- Not ergonomic for the interventional radiologist

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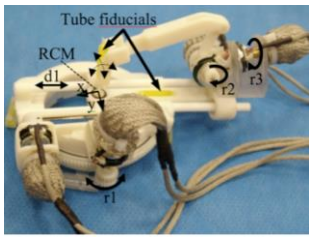
Robotically Assisted MRI-Guided Arthrography



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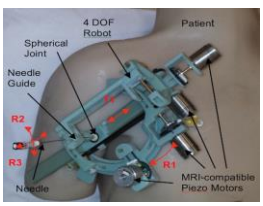
MRI Compatible Robot



- 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 (T_1, R_1)
  - Two for needle orientation (R_2, R_3)
- Accuracy: 2.95 +/- 2.04 mm

35/38 Monferadi et al. Conf Proc IEEE Eng Med Biol Soc. 2015

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ArthroBot Demonstration

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Conclusions

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

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