Towards Image-Guided Minimally Invasive Robotic Surgery for Partial Nephrectomy

Ghassan Hamarneh¹, Alborz Amir-Khalili², Masoud Nosrati¹, Ivan Figueroa², Jeremy Kawahara¹, Osama Al-Alao⁴, Abdulla Al-Ansari⁴, Julien Abi-Nahed³, Jean-Marc Peyrat³, Rafeef Abugharbieh²

¹Medical Image Analysis Lab, Simon Fraser University, Burnaby, Canada
²Biomedical Signal and Image Computing Lab, University of British Columbia, Vancouver, Canada
³Qatar Robotic Surgery Centre, Qatar Science & Technology Park, Doha, Qatar
⁴Urology Department, Hamad Medical Corporation, Doha, Qatar
OVERVIEW

1. Introduction to Robot-Assisted Partial Nephrectomy (RAPN)

2. Image-Guidance for Robotic Surgery

3. Conclusion
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KIDNEY CANCER

1. Robot-Assisted Partial Nephrectomy

- Kidney anatomy
- Kidney function is to filter the blood

- Stages of kidney cancer:

- Treatments: Chemotherapy / Radiotherapy / Surgery
RADICAL vs. PARTIAL NEPHRECTOMY

1. Robot-Assisted Partial Nephrectomy

- Renal mass > 4cm => radical nephrectomy
  + simpler surgical procedure

- Renal mass < 4cm => partial nephrectomy
  + avoidance of renal insufficiency
  - possible recurrence

- Remove cancerous tissue while sparing as much healthy tissue as possible to preserve kidney function and avoid recurrence
STEPS OF PARTIAL NEPHRECTOMY

1. Robot-Assisted Partial Nephrectomy
OPEN vs. MINIMALLY INVASIVE SURGERY

1. Robot-Assisted Partial Nephrectomy

- Less blood loss
- Less infections
- Faster recovery time
- Esthetic

Also for robotic surgery:
- dexterity/precision
- ergonomics
- enhanced 3D vision
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2. Image-Guidance for Robotic Surgery

- Pre-Operative CT/MR
- Stereo Endoscopic Video
- Laparoscopic US

Segmentation
PRE-OPERATIVE CT SEGMENTATION

2. Image-Guidance for Robotic Surgery

- Localize structures of interest in pre-operative scans
- Semi-automatic probabilistic segmentation based on Random Walker [Grady, 2006]
  - Input: seed points for each class (kidney, tumour, background)
  - Output: probability map to belong to a class

=> Segmentation + Uncertainties/Confidence
IMAGE-GUIDANCE IN ROBOTIC SURGERY

2. Image-Guidance for Robotic Surgery

- Biomechanical Modeling
- Segmentation
- Pre-Operative CT/MR
- Stereo Endoscopic Video
- Laparoscopic US
2. Image-Guidance for Robotic Surgery

- Predict deformations between pre-operative scan and surgery due to change of:
  - patient position (gravity)
  - pressure during insufflation (surfacic force load)

- Finite element method (FEM) using SOFA platform
  (with corotational tetrahedral formulation and a Eulerian implicit solver)

\[
M \ddot{u} + C \dot{u} + K u = F
\]

where
- \( u \) = displacement
- \( M \) = mass
- \( C \) = stiffness
- \( K \) = damping
- \( F \) = external force

=> Improvement of tumour localization prediction by 29%
IMAGE-GUIDANCE IN ROBOTIC SURGERY

2. Image-Guidance for Robotic Surgery

- Pre-Operative CT/MR
- Segmentation
- Biomechanical Modeling
- Surface Reconstruction
- Stereo Endoscopic Video
- Laparoscopic US
STEREO SURFACE RECONSTRUCTION

2. Image-Guidance for Robotic Surgery

- Build surface of actual surgical scene from stereo endoscopic camera

- Improvement of robustness [Bernhardt, 2012]

- Improvement of accuracy (+56%) using shape prior [Amir, 2013]

- Improvement of computation speed (up to x56) with GPU [Islam, 2013]
2. Image-Guidance for Robotic Surgery

- Multi-Modal Registration
- Biomechanical Modeling
- Segmentation
- Pre-Operative CT/MR
- Surface Reconstruction
- Stereo Endoscopic Video
- Laparoscopic US
PRE- AND INTRA-OPERATIVE IMAGE REGISTRATION

2. Image-Guidance for Robotic Surgery

- Align in the same reference frame CT segmentation and stereo endoscopic video

- “Level-set” formulation such that projected contours of the 3D model match the boundary of kidney and tumour in left and right camera

![Initial Pose](image1.png) ![Rigid Registration](image2.png) ![Deformable Registration](image3.png) ![Video Sequence](image4.png)
IMAGE-GUIDANCE IN ROBOTIC SURGERY

2. Image-Guidance for Robotic Surgery

Augmented Reality Visualization

Multi-Modal Registration

Biomechanical Modeling

Segmentation

Pre-Operative CT/MR

Surface Reconstruction

Stereo Endoscopic Video

Laparoscopic US
AUGMENTED REALITY VISUALIZATION

2. Image-Guidance for Robotic Surgery

- Guide surgeon in localizing tumour boundaries

✓ Simple way to display uncertainties without obstructing surgeon’s view

Mesh of most probable boundary
Most probable contour
Range of iso-probabilities
Color-coded uncertainties [Amir, 2013]
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3. CONCLUSION

Contributions:

✓ Proof-of-concept framework for uncertainty encoded augmented reality system that fuses pre-operative data into surgical scene

✓ Collection of valuable patient data in the context of RAPN: CT/MR/US + laparoscopic US + stereo video

Future Work:

✓ Use laparoscopic US
✓ Compute and fuse uncertainties from all steps
✓ Biomechanical modeling during surgery
✓ Full system integration and validation

More info: http://igrs.cs.sfu.ca/
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Thank You

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