LABORATORY FOR Computational Sensing + Robotics

Improving The Transparency Of The Galen Robot

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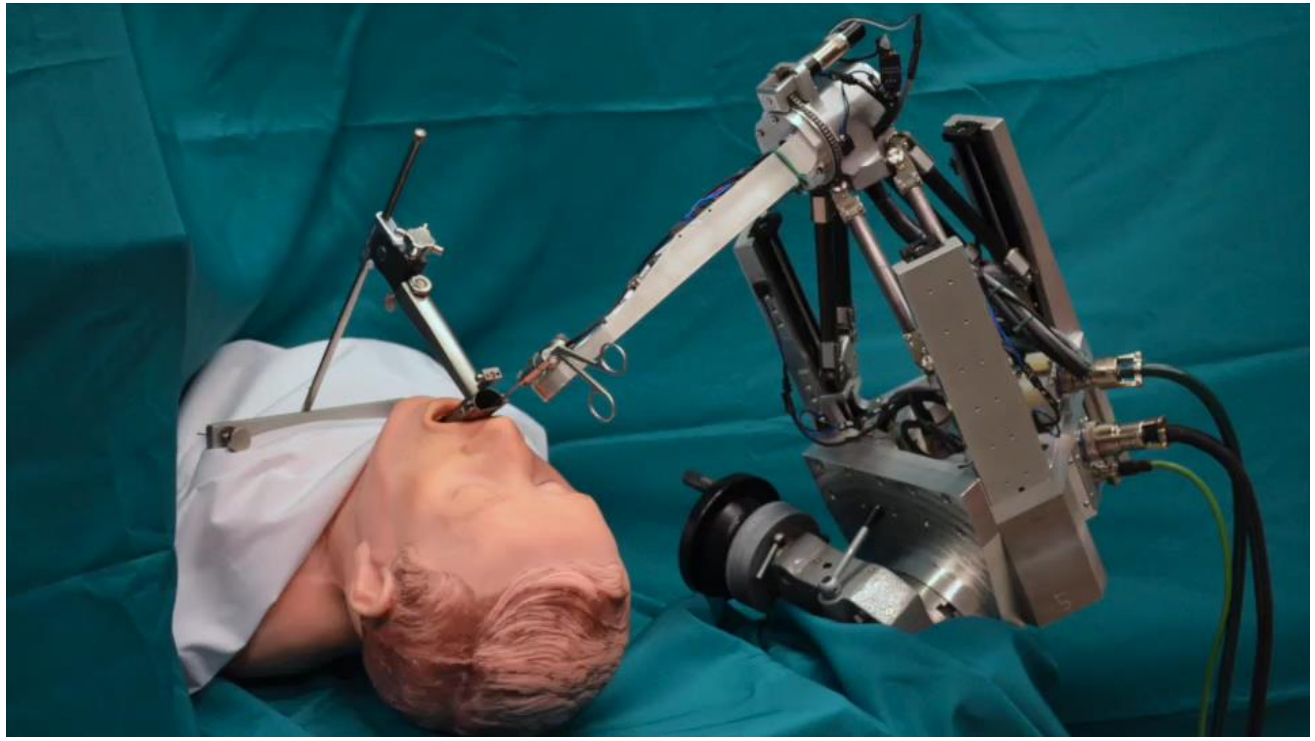
Background

- The Galen Robot (Mk-2) is a prototype 5-DoF Stewart Platform based robotic manipulator intended for surgical use.
- 6-axis F/T sensor mounted between the robot and the end effector (wrist) for hand-over-hand control mode.
- Steady platform, elimination of hand tremors and enforcement hard or soft limits.
- The tool is typically, but not limited to, a surgical drill intended for cutting bone.

Relevance

Shift towards minimally invasive surgery presents new challenges such as reduced visibility, limited working space near sensitive anatomy, poor sensory feedback and difficulty of manipulation.

Need for stable surgical robotic platforms to efficiently execute tasks.



Video Credit:

[10] A. S. Ding, S. A. Capostagno, C. R. Razavi, Z. Li, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Volumetric Accuracy Analysis of Virtual Safety Barriers for Cooperative-Control Robotic Mastoidectomy", *Otology & Neurotology,* vol. 42- 10, pp. e1513-1517, 2021.

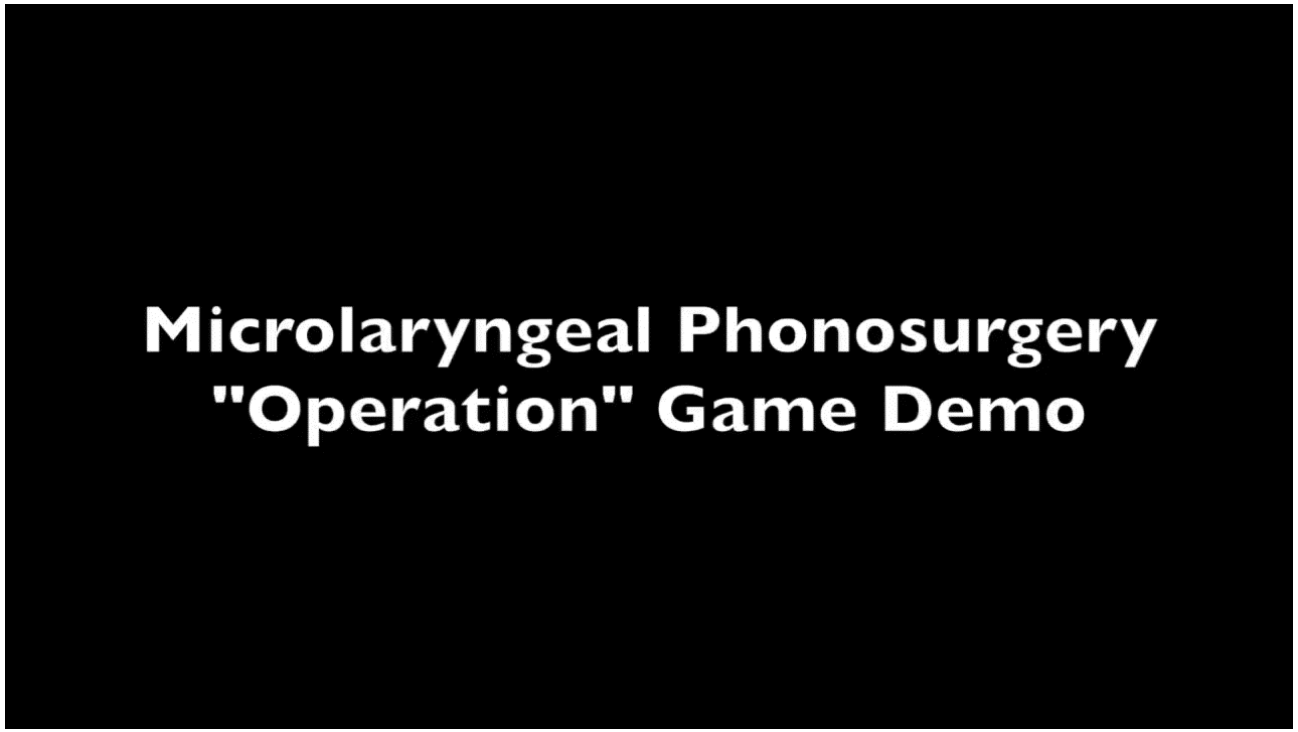
Project Goal

The goal of this project is to improve the transparency of the Galen hand-over-hand surgical robot i.e. to make the tool feel ‘weightless’ in the hands of the operator. Currently, the feel of the tool while used in the hand-over-hand control mode is sub-par and sluggish. This project aims to improve this ‘feel’ and make the robot more responsive to operator force input.

Technical Approach – Establishing Metrics

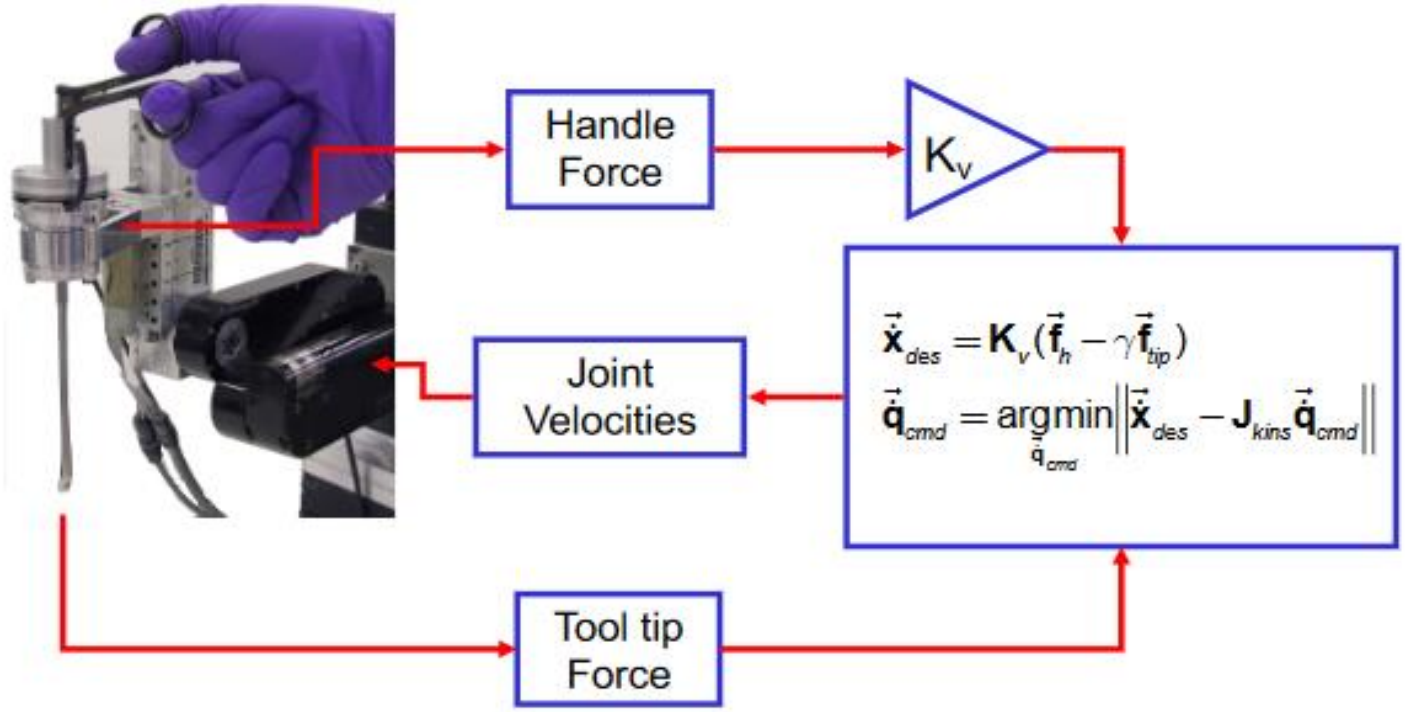
- An objective method to test improvement must be determined.

1. Spiral game time
2. Force magnitude
3. Operator rating
4. Conventional parameters



Video Credit:
[21] L. Akst, K. Olds, M. Balicki, P. Chalasani, and R. Taylor, "Robotic Microlaryngeal Phonosurgery: Testing of a “Steady-Hand Platform", Laryngoscope, vol. 128-, pp. 126-132, Jan., 2018. May 12 10.1002/lary.26621, PMID: 28498632

Technical Approach – Tuning Gains



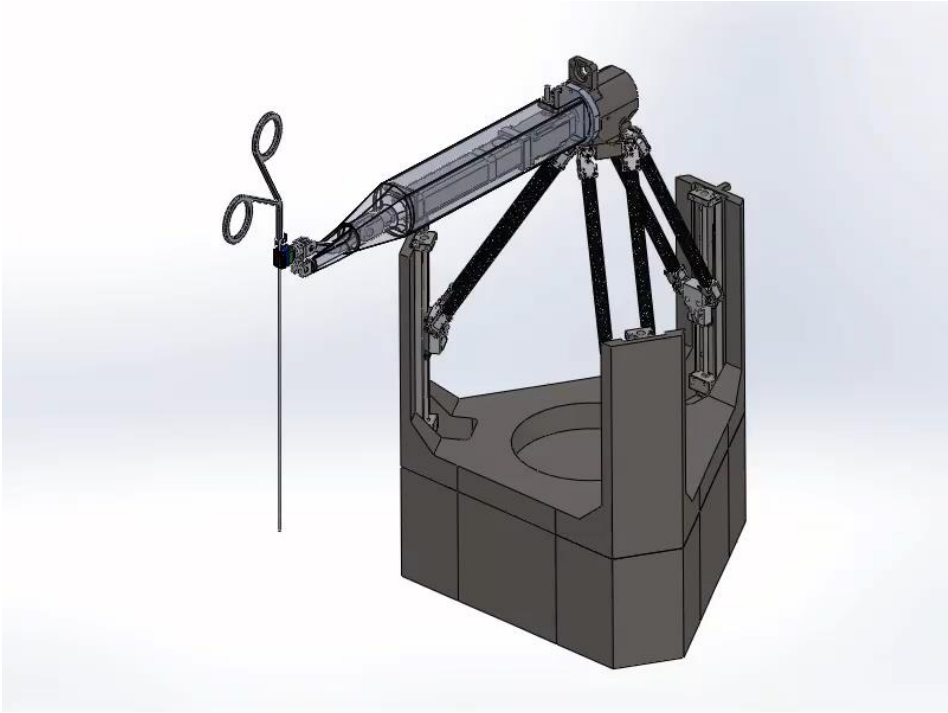
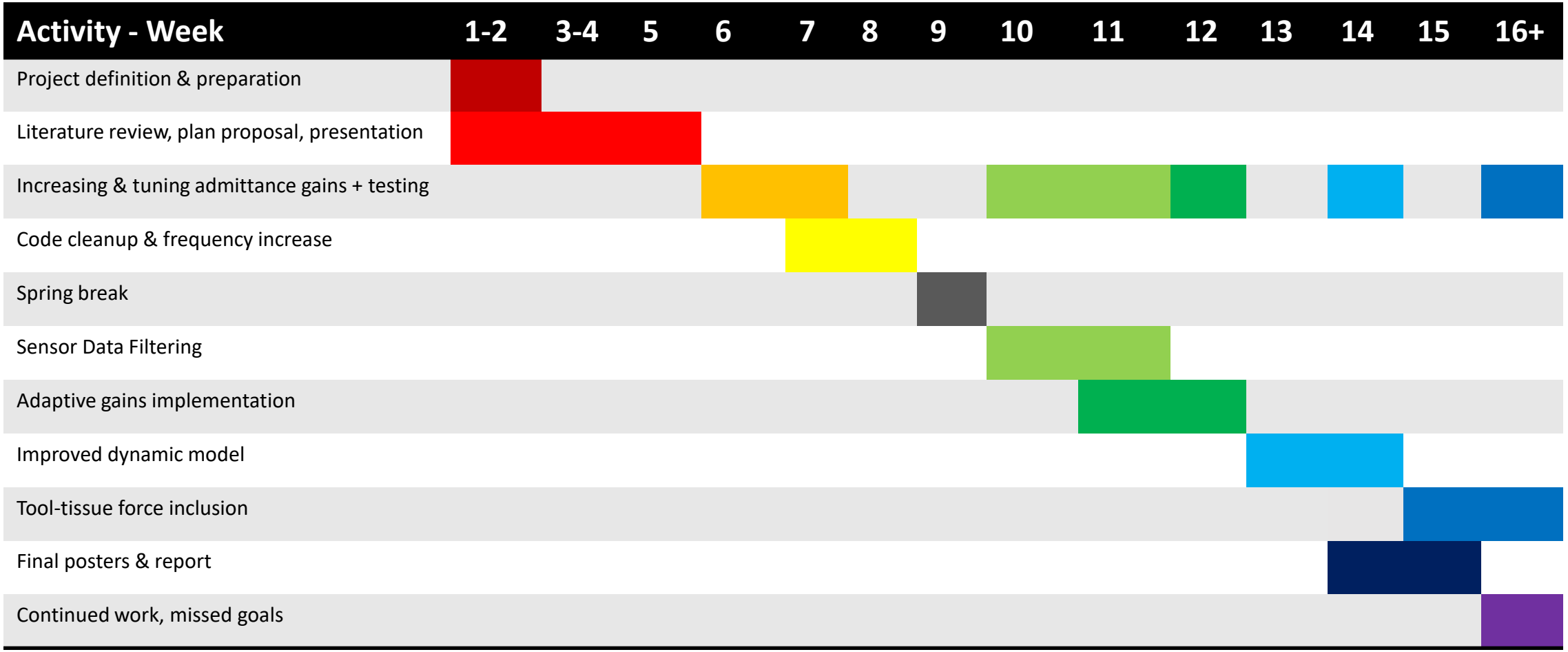


Image: Admittance control block diagram. Source: CIS-1 lecture notes, R.H. Taylor, 2021

Deliverables

- Minimum:
  1. Code cleanup & corrected control loop timing
  2. Tuned admittance gain at maximum stable limit
- Expected:
  1. Mean sensor forces reduced by 50%
  2. Experimental data and operator testing result analytics
- Maximum:
  1. Mean sensor forces reduced by 75%
  2. Implemented adaptive gains control loop
  3. Control loop with wrist force and tool-tissue force

Timeline


Activity - Week
1-2
3-4
5
6
7
8
9
10
11
12
13
14
15
16+
Project definition & preparation
Literature review, plan proposal, presentation
Increasing & tuning admittance gains + testing
Code cleanup & frequency increase
Spring break
Sensor Data Filtering
Adaptive gains implementation
Improved dynamic model
Tool-tissue force inclusion
Final posters & report
Continued work, missed goals

Milestones

Date	Milestone
Mar 15th	Established transparency metrics Collected data to establish baseline
Mar 27th	Experiments show improved transparency by 20%
April 10th	Transparency improved 50%
April 26th	Transparency improved 75% Tool-tissue force compensation implemented

Dependencies

Dependency	Contact	Status	Plan of action	Expected date	Consequence if not fulfilled	Contingency
Functioning robot, PC	Dr. Taylor	Fulfilled	-	-	Project cannot continue	New project to fix robot/use Mk1
Access to Mock OR, code repos, documentation	Dr. Taylor, Florin	Partly fulfilled	Contacted Florin for code access	Mar 4th	Prevented from code access at home	Access code and documentation from Mock OR
Functioning tool for robot	Anna, Adnan	Fulfilled	-	-	None	Will use different tool
Availability of robot	Anna	Ongoing	Book time on robot in advance	-	Restricted to WFH, limited testing & feedback	Use sharepoint to schedule time
Availability of mentors and surgeons for testing	Dr. Galaiya, Adnan	Ongoing	Schedule time in advance	-	Unable to get constructive feedback	Test robot with mentors, peers

Management Plan

- Weekly progress report meetings with Dr. Taylor on Wednesdays.
- Short weekly meetings on Fridays with Adnan to discuss technical details and next steps.
- All code managed in existing BitBucket Repo.
- Documentation and presentations to be stored in JHU Galen OneDrive.
- Communication with mentors and peers over slack.

Reading List

[1] F. Creighton, C. Razavi, P. Wilkening, R. Taylor, and C. JP, "Image-Guided Mastoidectomy with the Robotic ENT Microsurgery System.", (abstract) in AAO-HNSF Annual Meeting, Atlanta, Sept 15-18, 2018. (abstract)

[2] C. R. Razavi, F. X. Creighton, P. R. Wilkening, J. Peine, R. H. Taylor, and L. M. Akst, "Real-time robotic airway measurement: An additional benefit of a novel steady-hand robotic platform (abstract)", in Combined Otolaryngology Spring Meetings (COSM), Baltimore, Maryland, April 18-22, 2018.

[3] C. R. Razavi, P. R. Wilkening, R. Yin, N. Lamaison, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Applied Force during Piston Prosthesis Placement in a 3D-Printed Model: Freehand vs Robot-Assisted Techniques", *Otolaryngology–Head and Neck Surgery*, p. (epub ahead of print), 2018. Dec. 4 https://doi.org/10.1177/0194599818815144

[4] C. R. Razavi, P. R. Wilkening, R. Yin, N. Lamaison, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Applied Force during Piston Prosthesis Placement in a 3D-Printed Model: Freehand vs Robot-Assisted Techniques", (abstract) in AAO-HNSF Annual Meeting, Atlanta, Sep 15-18, 2018. (abstract) https://doi.org/10.1177/0194599818815144

[5] C. Razavi, A. Berges, M. Shahbazi, R. Taylor, J. Carey, and F. Creighton, "Evaluation of Patient Head Motion During Otologic Surgery: An Initial Evaluation for Development of a Dynamic Endoscope Manipulator", in World Congress of Endoscopic Ear Surgery 3.0, Boston,, June 13-15, 2019. p. (abstract in electronic proceedings).

[6] C. R. Razavi, F. X. Creighton, P. R. Wilkening, J. Peine, R. H. Taylor, and L. M. Akst, "Real-time robotic airway measurement: An additional benefit of a novel steady-hand robotic platform", *The Laryngoscope*, pp. 324-329, Feb., 2019. Nov. 15, 2018 10.1002/lary.27435

[7] C. R. Razavi, P. R. Wilkening, R. Yin, S. R. Barber, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Image-Guided Mastoidectomy with a Cooperatively Controlled ENT Microsurgery Robot", *Otolaryngology–Head and Neck Surgery*, p. 0194599819861526, 2019. https://doi.org/10.1177/0194599819861526 10.1177/0194599819861526

[8] Patent R. H. Taylor and F. X. Creighton, "Safety feature for use with robotically manipulated endoscopes and other tools in otolaryngology and neurosurgery", PCT, Filed 6 Feb, Issued

[9] A. J. Berges, C. Razavi, M. Shahbazi, R. Taylor, J. P. Carey, and F. X. Creighton, "Characterization of Patient Head Motion in Otologic Surgery: Implications for TEES", *American Journal of Otolaryngology,* vol. 42- 1, p. 102827, Jan-Feb, 2021. 13 Nov 2020 doi.org/10.1016/j.amjoto.2020.102827

[10] A. S. Ding, S. A. Capostagno, C. R. Razavi, Z. Li, R. H. Taylor, J. P. Carey, and F. X. Creighton, "Volumetric Accuracy Analysis of Virtual Safety Barriers for Cooperative-Control Robotic Mastoidectomy", *Otology & Neurotology,* vol. 42- 10, pp. e1513-1517, 2021.

[11] A. S. Ding, A. Lu, Z. Li, D. Galaiya, J. H. Siewerdsen, R. H. Taylor, and F. X. Creighton, "Automated Registration-Based Temporal Bone Computed Tomography Segmentation for Applications in Neurotologic Surgery", *Otolaryngology–Head and Neck Surgery*, p. 01945998211044982, 2021. 7 Sept. https://doi.org/10.1177/01945998211044982 10.1177/01945998211044982

[12] Z. Li, X. Liu, N. Drenkow, A. Ding, F. X. Creighton, R. H. Taylor, and M. Unberath, "Revisiting stereo depth estimation from a sequence-to-sequence perspective with transformers", in Proc. IEEE/CVF International Conference on Computer Vision, 2021. pp. 6197-6206.

[13] A. Munawar, Z. Li, P. Kunjam, N. Nagururu, A. S. Ding, P. Kazanzides, T. Looi, F. X. Creighton, R. H. Taylor, and M. Unberath, "Virtual reality for synergistic surgical training and data generation", *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, pp. 1-9, 2021. https://doi.org/10.1080/21681163.2021.1999331 10.1080/21681163.2021.1999331

[14] C. Razavi, D. Galaiya, S. Vafaee, R. Yin, J. P. Carey, R. H. Taylor, and F. X. Creighton, "Three dimensional printing of a low-cost middle-ear training model for surgical management of otosclerosis", *Laryngoscope investigative otolaryngology,* vol. 6- 5, pp. 1133-1136, 2021.

[15] K. Olds, *Robotic Assistant Systems for Otolaryngology-Head and Neck Surgery,* PhD thesis in Biomedical Engineering, Johns Hopkins University, Baltimore, March 2015.

[16] K. C. Olds, "Global Indices for Kinematic and Force Transmission Performance in Parallel Robots", *IEEE Transactions on Robotics,* vol. 31- 2, pp. 494-500, April, 2015.

[17] A. L. Feng, C. R. Razavi, P. Lakshminarayanan, Z. Ashai, K. Olds, M. Balicki, Z. Gooi, A. T. Day, R. H. Taylor, and J. D. Richmon, "The robotic ENT microsurgery system: A novel robotic platform for microvascular surgery", *The Laryngoscope,* 127, pp. 2495-2500, November, 2017.

[18] Z. Li, A. Gordon, T. Looi, J. Drake, C. Forrest, and R. H. Taylor, "Anatomical Mesh-Based Virtual Fixtures for Surgical Robots", in International Conference on Intelligent Robots and Systems (IROS), Las Vegas, Oct. 25-29, 2020. p. (accepted; draft copy at https://arxiv.org/abs/2006.02415).

[19] Z. Li, X. Liu, N. Drenkow, A. Ding, F. X. Creighton, R. H. Taylor, and M. Unberath, "Revisiting stereo depth estimation from a sequence-to-sequence perspective with transformers", in Proc. IEEE/CVF International Conference on Computer Vision, 2021. pp. 6197-6206.

[20] A. Munawar, Z. Li, P. Kunjam, N. Nagururu, A. S. Ding, P. Kazanzides, T. Looi, F. X. Creighton, R. H. Taylor, and M. Unberath, "Virtual reality for synergistic surgical training and data generation", *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, pp. 1-9, 2021. https://doi.org/10.1080/21681163.2021.1999331 10.1080/21681163.2021.1999331

[21] L. Akst, K. Olds, M. Balicki, P. Chalasani, and R. Taylor, "Robotic Microlaryngeal Phonosurgery: Testing of a “Steady-Hand Platform", Laryngoscope, vol. 128-, pp. 126-132, Jan., 2018. May 12 10.1002/lary.26621, PMID: 28498632

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Questions

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