Project16

VR Guided Surgery
SDF based guidance and safety

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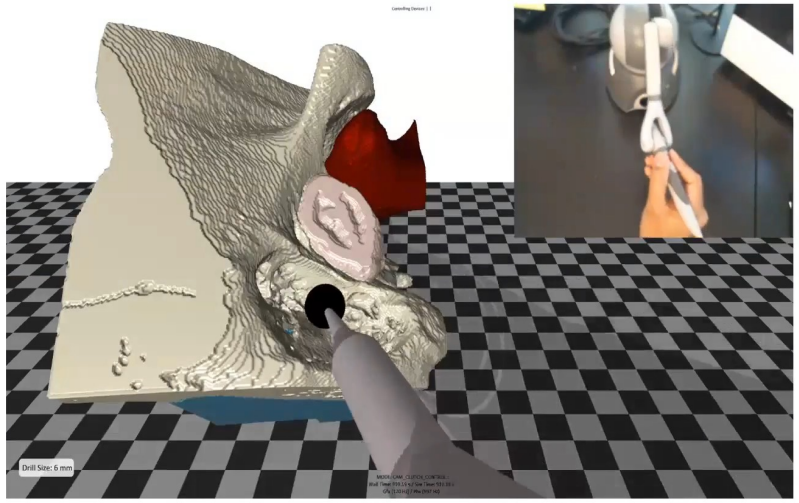
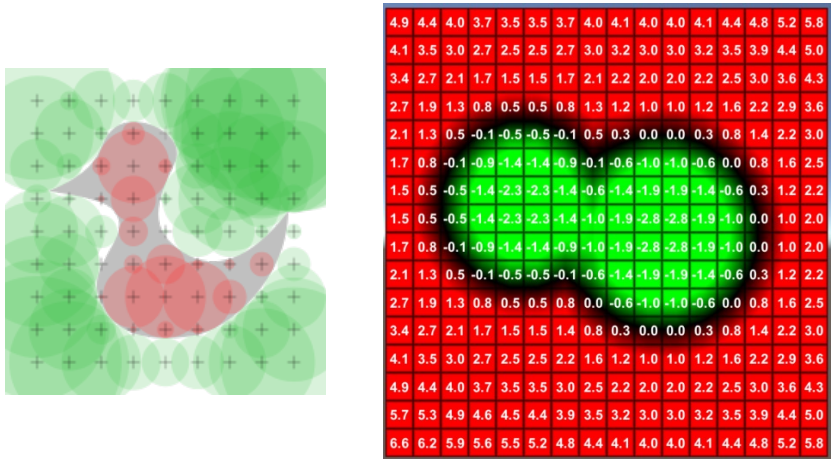
Project Summary

Mastoidectomy Procedure

- Require high precision
- Preserve important structures



Volumetric Drill Simulation [1]



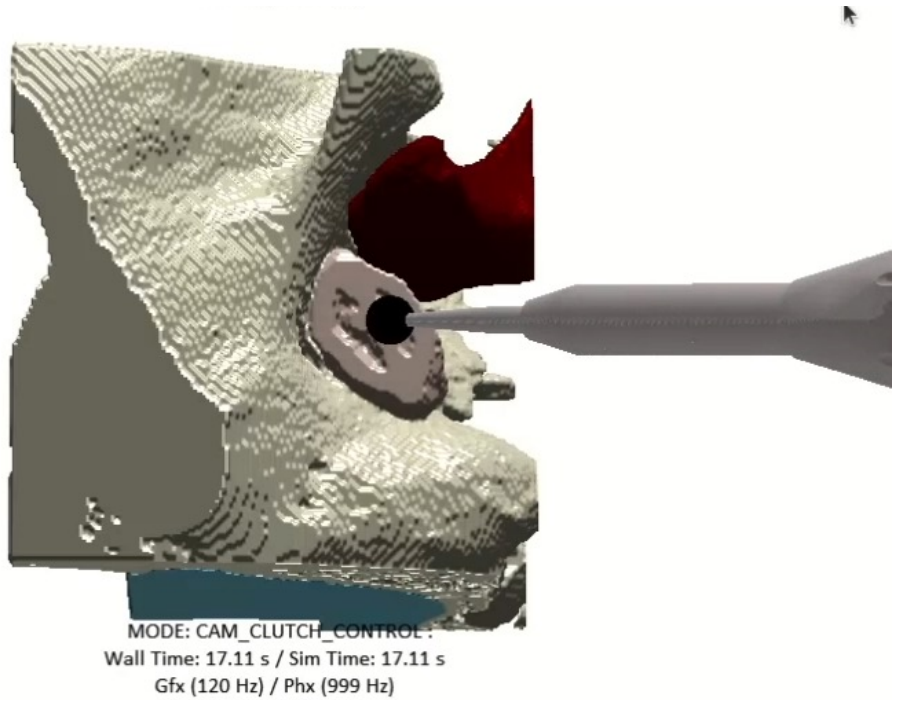
Signed Distance Field [2]

Goal: Evaluate the effectiveness of feedback modalities based on SDFs to improve situational awareness on virtual drilling.

Paper 1 detail

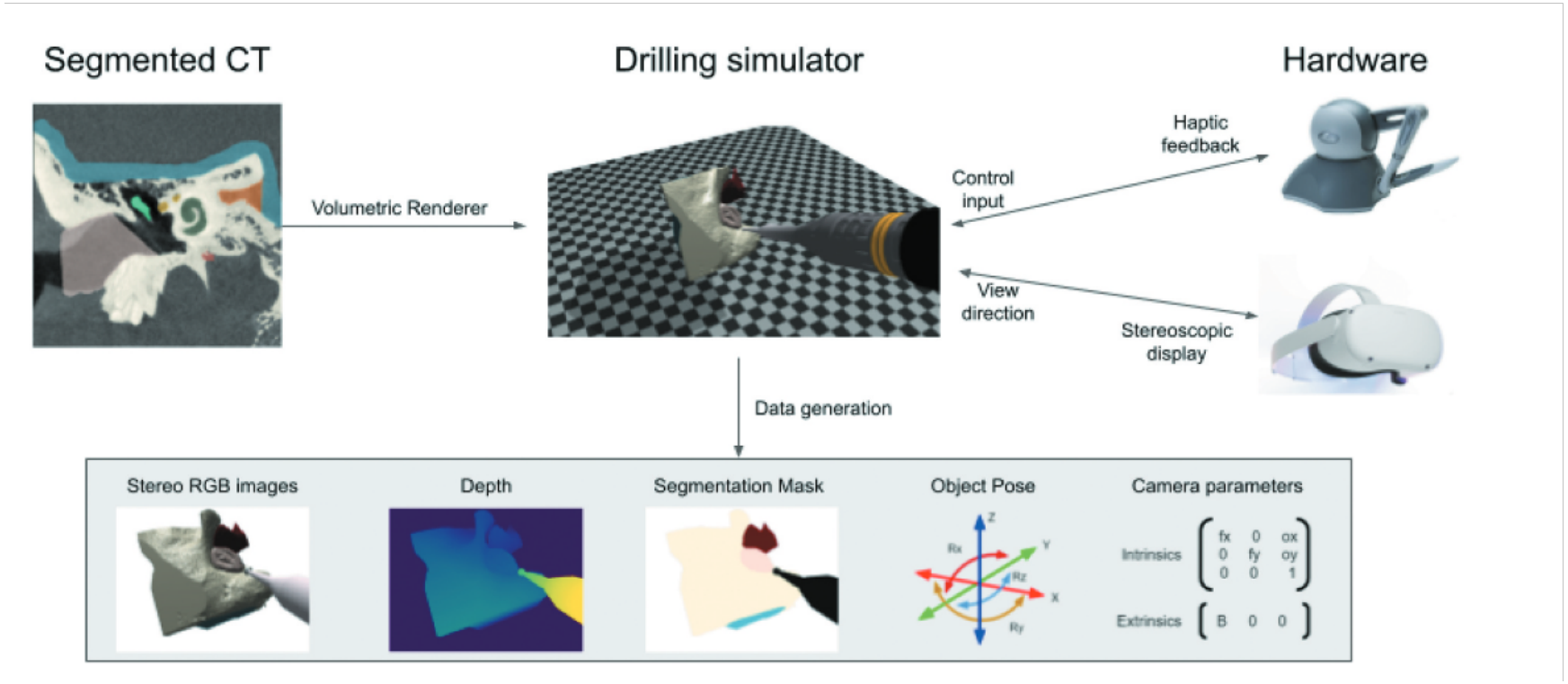
- **Title:** Virtual Reality for Synergistic Surgical Training and Data Generation
- **Authors:** Adnan Munawar, Zhaoshuo Li, Punit Kunjam, Nimesh Nagururu, Andy S. Ding, Peter Kazanzides, Thomas Looi, Francis X. Creighton, Russell H. Taylor, Mathias Unberath
- **Journal:** Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization

- **Relevance**
  - Description of skull surgery simulation.
  - Detailed description of software architecture.
  - Description of the clinical task.
  - key to providing a seamless integration of our SDF-based feedback mechanisms with the current simulation.



Technical Approach(1)

- **Asynchronous Multibody Framework Plus (AMBF+)**
  - Generate relevant data in real-time
    (e.g RGB stereo images, depth, and object pose)
  - Propose a plugin to customize the environment



Technical Approach(2)

- **Anatomy Loading**
  - input sliced CT volume
  - Generate voxel grid anatomy in the simulation

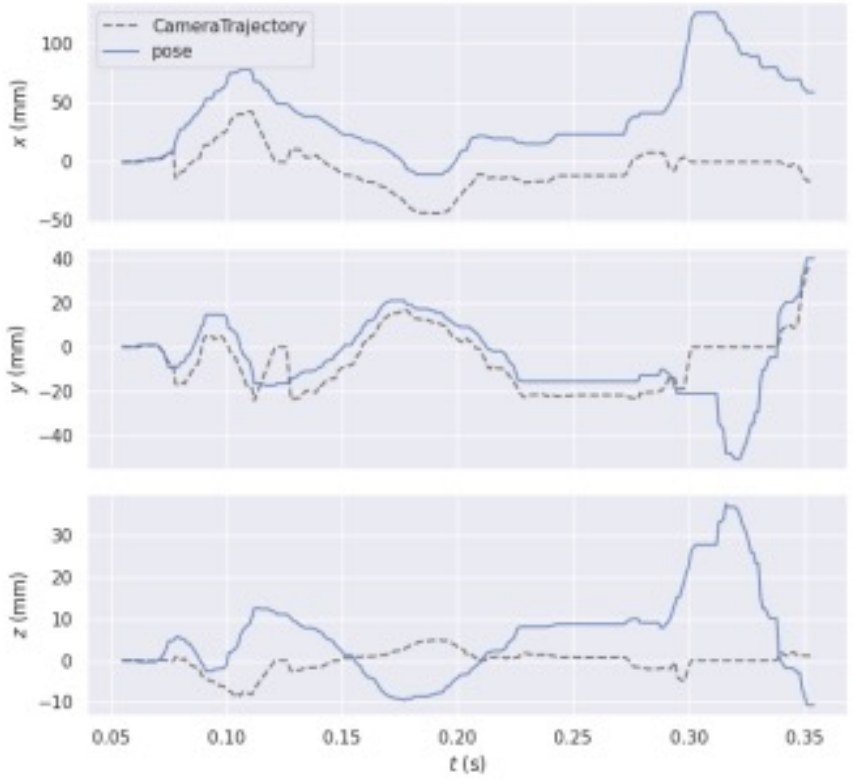
- **Stereo display and VR support**
  AMBF+ has support for Virtual Realty(VR) Head Mount Display(HBD) by generating a pair of stereoscopic images.

- **Haptic device**
  CHAI3D's finger proxy collision algorithm [3] to provide haptic feedback by simulating the collision with the surface of the volume.

Experiment 1

- **Goal**: Evaluation of state-of-the-art pose tracking algorithms with data produced by the simulation.
- **Algorithm**: ORB SLAM V3.
- **Analysis**: Calculate selected algorithm's precision under two conditions (Camera movement & tools movement)

- **Results summary:**
  - The analyzed pose tracking algorithm is not robust to camera motions.



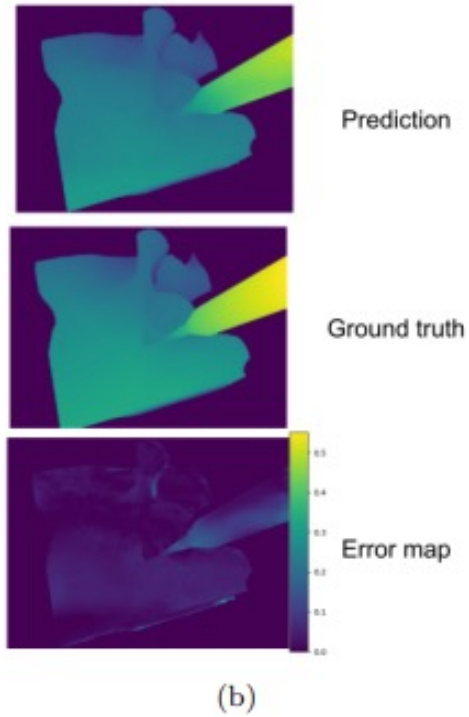
(a)

	Translation Error (mm)	Rotation Error (deg)
Moving camera	40.97 ± 22.40	8.44 ± 3.07
Moving drill	8.1E-1 ± 9.1E-1	3.2E-3 ± 3.6E-3

Experiment 2

- **Goal**: Evaluation of deep learning-based depth estimation algorithm.
- **Algorithm**: Stereo depth network STTR.
- **Analysis**: Calculated a depth estimate of the selected network.

- **Results summary:**
  - The trained depth network generalizes to changes in the anatomical structure. (Even when training on a single anatomy)
  - The resulting depth maps have an error 1.98mm.



(b)

Critical Review

- **Pros**:
  - Paper does a good job at demonstrating the utility of the simulator's data for testing a development computer vision algorithms.

- **Cons:**
  - Paper lacks experiments that proves the training/educational value of the simulated environment.

- **Key Takeaway:**
  - Our work complements this paper by building tools that will make the simulation a better training tool for residents.
  - Evaluate the usefulness of the simulation as surgical training tool.

Paper 2 detail

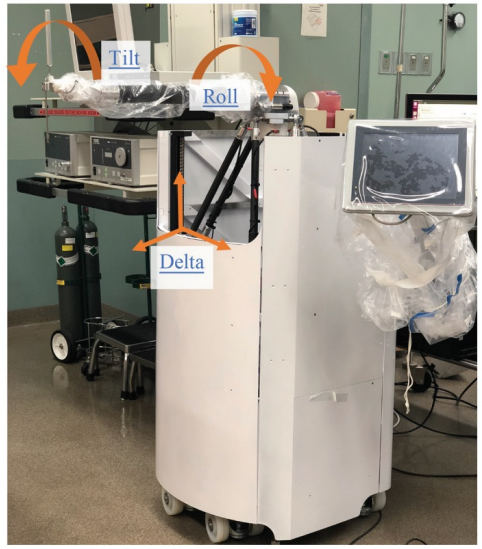
- **Title:** Image-Guided Mastoidectomy with a Cooperatively Controlled ENT Microsurgery Robot
- **Authors:** Christopher R. Razavi, Paul R. Wilkening , Rui Yin , Samuel R. Barber, Russell H. Taylor, John P. Carey, and Francis X. Creighton
- **Journal:** Short Scientific Communication—Otology and Neurotology

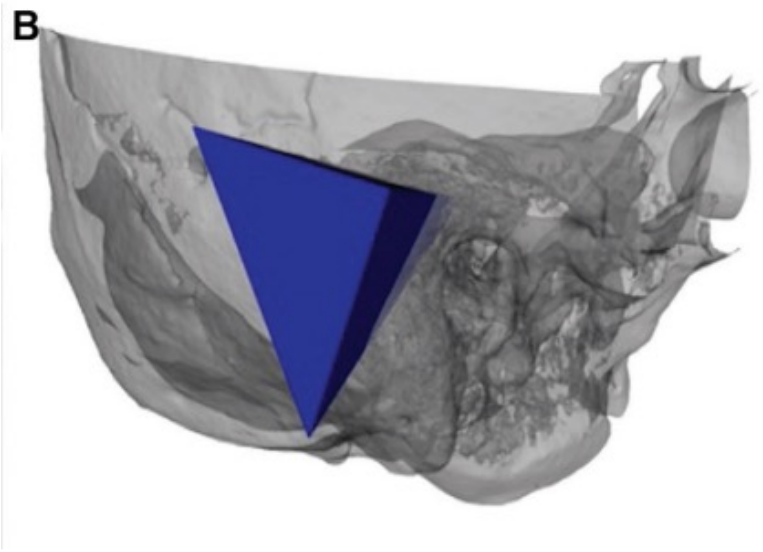
- **Relevance**
  - Description of the clinical task.
  - Baseline for the robot aided mastoidectomy
  - User study design

Technical Approach

- **5DOF cooperative Robotic ENT Microsurgery System**
  - Enhanced operative precision with dampening of tremor

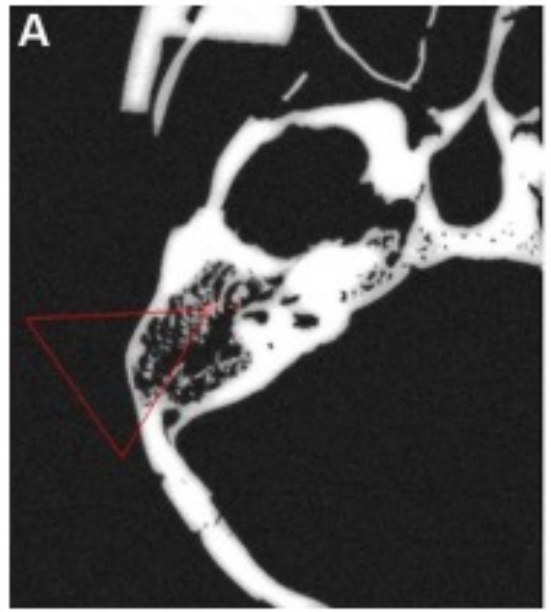
- **Forbidden Regional Virtual Fixtures**
  - Demarcate surgical workspace boundaries and prevent motion into undesired areas





Experiment

- **Task:** Drilling on right temporal bone model phantom while being assisted by virtual fixtures.
- **Virtual fixtures:** After an image registration procedure, 3 intersecting planes were used to delimited the regions where the drill could move safely.
- **Protocol:** Untrained user performed the drilling experiment 5 times while being assisted by the virtual fixtures.
- **Evalution:** Success of the procedure was evaluated by fellowship-trained neurotologist who was not present during the experiment.



Critical Review

- **Pros**
  - Successfully demonstrated the feasibility of the robot system and the virtual fixture assistance.
  - Increase safety and reduce task completion time

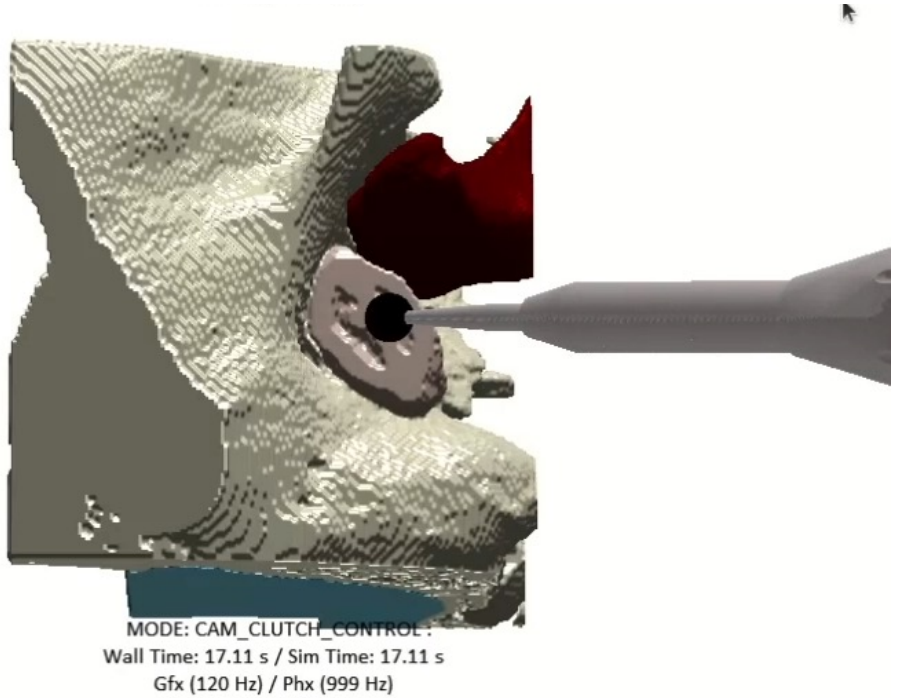
- **Cons**
  - No quantitative discussion about the assistance.
  - No comparison with other control

- **Key Takeaway**
  - User study design
  - Baseline for the robot aided mastoidectomy

Conclusion

- AMBF+ is a flexible simulation environment that can potentially be used to benchmark computer vision algorithms and develop surgical skills.

- Assistive robotic tools such as virtual fixtures can make a big difference on a procedure to improve safety and develop situational awareness.



References

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

[2] Razavi, C. R., Wilkening, P. R., Yin, R., Barber, S. R., Taylor, R. H., Carey, J. P., & Creighton, F. X. (2019). Image-guided mastoidectomy with a cooperatively controlled ENT microsurgery robot. *Otolaryngology–Head and Neck Surgery*, *161*(5), 852–855. https://doi.org/10.1177/0194599819861526

[3] Diego Ruspini and Oussama Khatib. Haptic display for human interaction with virtual dynamic environments. Journal of Robotic Systems, 18(12):769–783, 2001.