JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Tele-operation Control of a High Dexterity Robot for Vitreoretinal Surgery

- Team 21: Xiao Wei
- Mentors: Mojtaba Esfandiari, Adnan Munawar, Dr. Iulian Iordachita

Project Summary

Goal: To implement a simulation of a combined teleoperation system using the Asynchronous Multi-Body Framework (AMBF)

- Build a model of the snake robot in Blender based on the CAD drawing and connect it in the simulation
- Develop an AMBF plugin to manipulate the snake robot attached to SHER and interact with the OCT scan of the eye
- Develop a control algorithms to control the snake robot using the feedback of haptic device

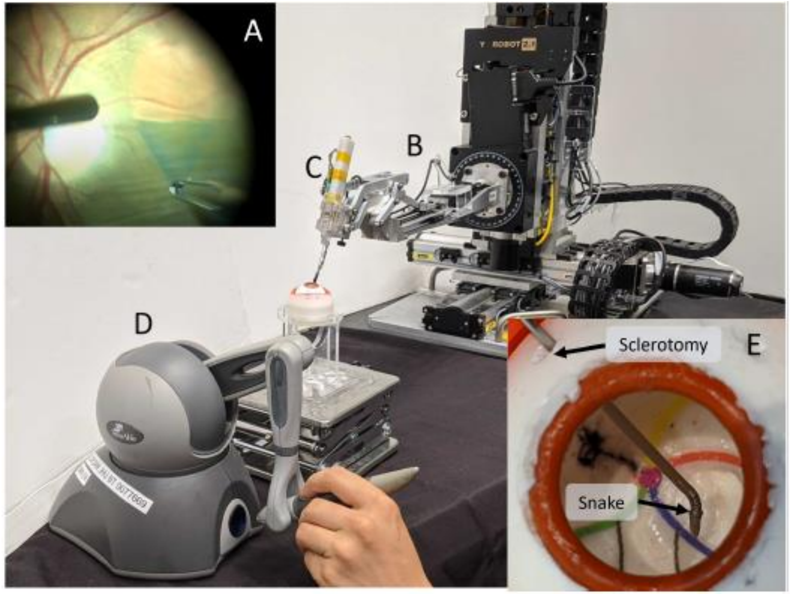


Fig. Envisioned high dexterity intraocular manipulator (Shi, K., 2022)

Paper detail

- **Title:** Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond
- **Authors:** Munawar A, Li Z, Nagururu N, et al
- **Journal:** arXiv preprint arXiv:2302.13878 (2023)
- **Relevance:**
  - Apply the volumetric drilling simulation for certain kind of surgery
  - Control the virtual drill using the haptic device

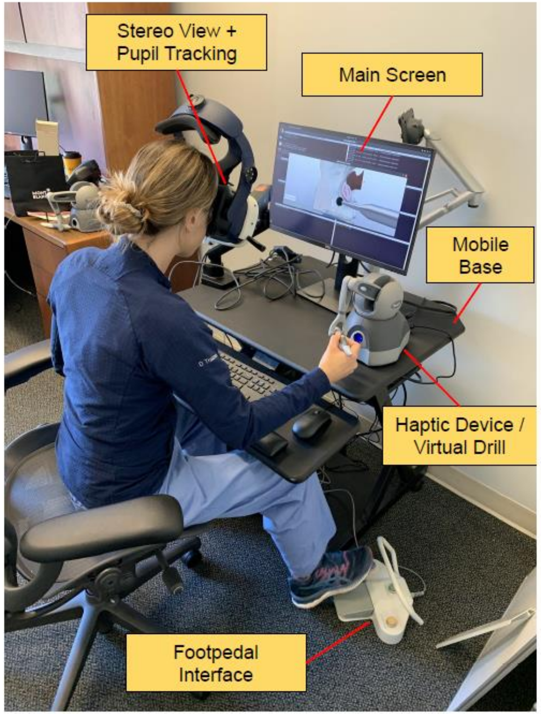


Fig. Hardware setup (Munawar, A., 2023)

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Technical Approach

- FIVRS comprises of several software and hardware components aimed at providing
  - a realistic user interface
  - visual fidelity
  - extensive data generation and recording

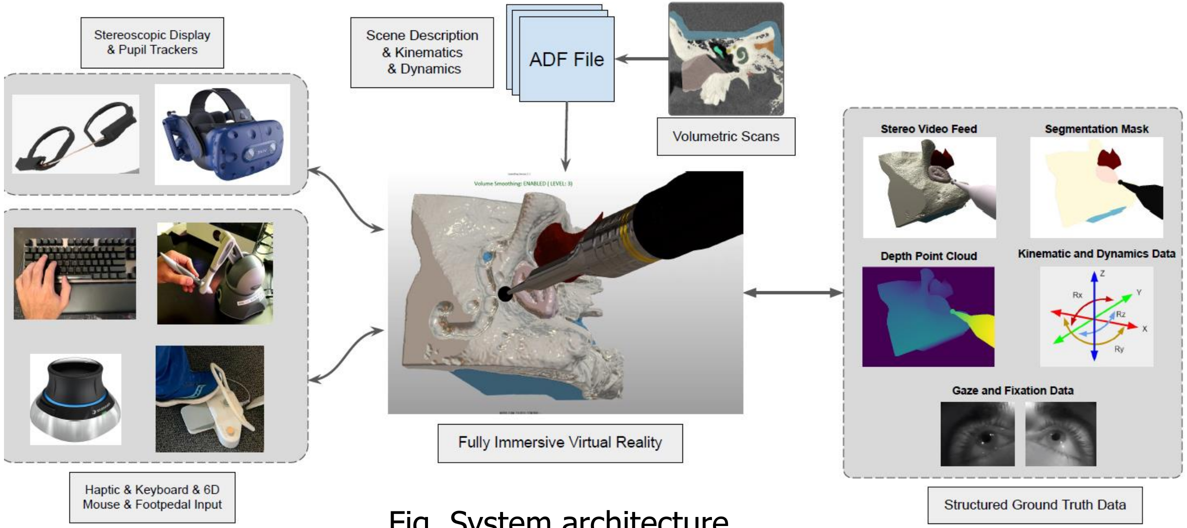


Fig. System architecture

User Interaction and Interface

- **Head Mounted Display**
  - Use a VR headset to resemble a high-resolution stereo microscope used in traditional skull-base surgeries
- **Modelling drill types**
  - 4 drill types (1, 2, 4, 6 mm)
  - Adjust different bone removal rate (BRR) from surgeon feedback
- **GUI**
  - Deploy a user-friendly interface instead of typing in the Linux command line

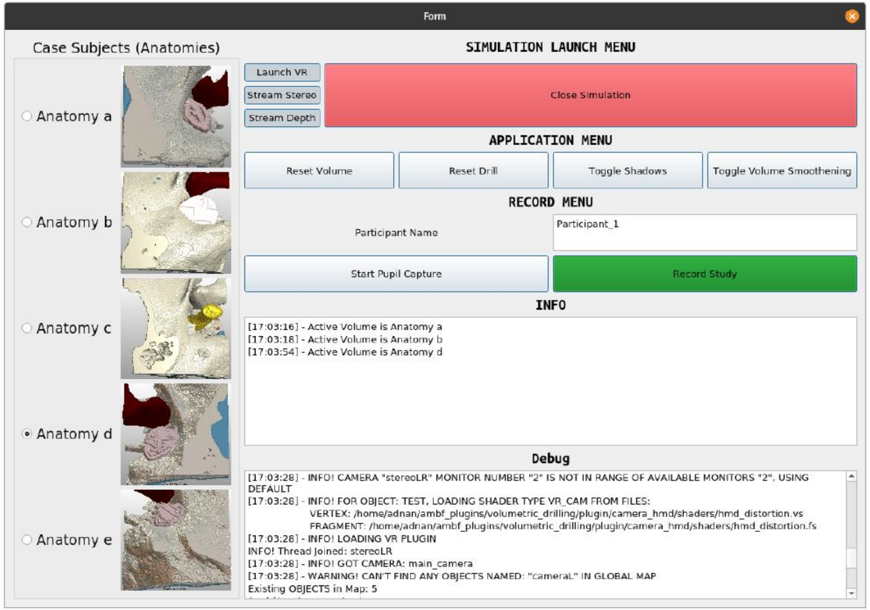


Fig. Graphical User Interface (GUI)

Visual Fidelity

Improvement due to surgeons' feedback:

1) unnatural artifacts and edges on the anatomical structures
2) challenges in accurately perceiving depth
3) mediocre illumination and shading

- **Smoothing**
  - A volumetric ray casting approach implemented on the GPU and summarized in Algorithm 1
- **Shadow**
  - Implemented shadow mapping to the rendered volume to improve depth perception

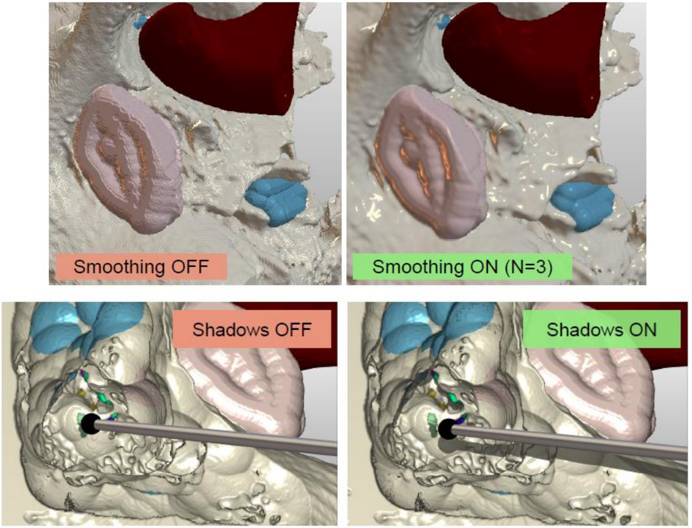


Fig. Comparison of smoothing(up)/shadows(down) off and on

Algorithm 1 Online Volume Smoothing

$\delta\vec{p} = \vec{1} * (N-1)/2.0$ ▷ $N :=$ Sample Threshold $\in \mathbb{R}$

$\vec{\phi} = \vec{1}/[c_x, c_y, c_z]'$ ▷ $c_x, c_y, c_z :=$ Number of Voxels along X, Y and Z

$\vec{p}_{iso} := Raycast(\vec{v})$ ▷ $\vec{v} :=$ View Ray. $\vec{p}_{iso}$ refined by interval bisection

$\vec{\eta} = \vec{0}$ ▷ Smoothed Normal

for $x < N$ **do**

    for $y < N$ **do**

        for $z < N$ **do**

            $\vec{p}_{offset} = [x, y, z]'$

            $\vec{p}_{sample} = \vec{p}_{iso} + (\vec{p}_{offset} - \delta\vec{p}) * \vec{\phi}$

            $\vec{\eta} = \vec{\eta} + \nabla(\vec{p}_{sample})$ ▷ $\nabla :=$ Gradient from Central Difference

        end for

    end for

end for

$\vec{\eta} = normalize(\vec{\eta})$

Data Generation and Management

- **Importing Anatomical Scans**
  - Develop a program that converts the data in “seg.nrrd” format to an array of images to ease the incorporation into FIVRS
- **Ground Truth Data Storage**
  - includes a pair of videos (from stereo cameras), real-time depth point cloud, segmentation mask, and kinematic and dynamics data of scene objects

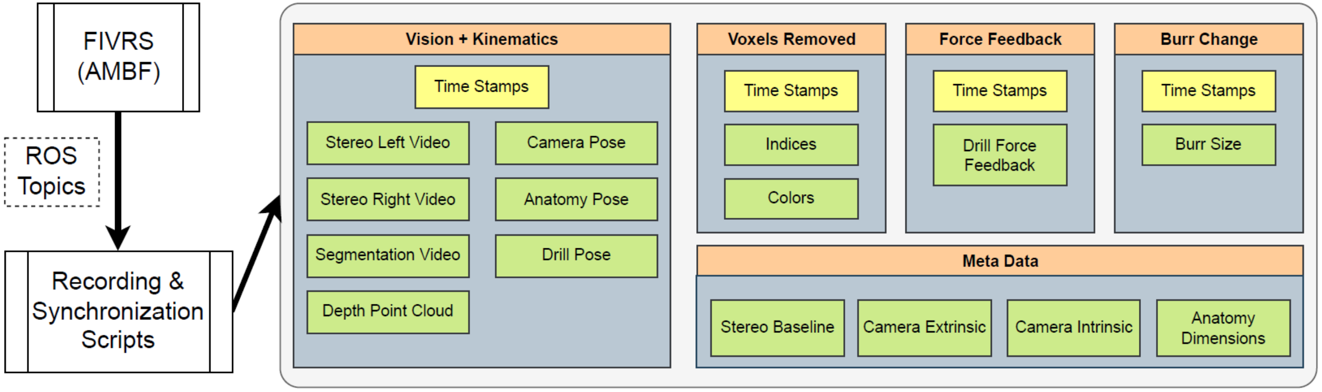
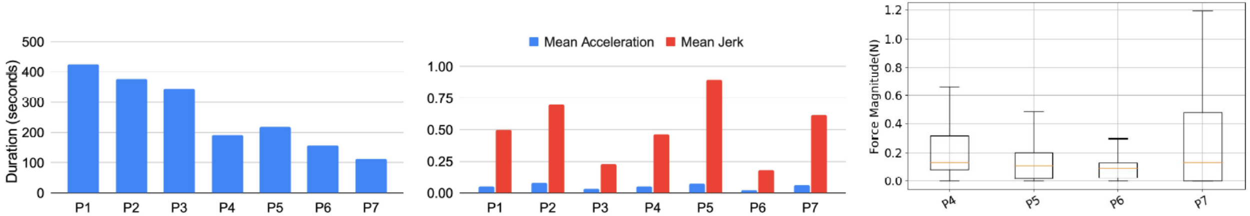


Fig. Asynchronous data from FIVRS

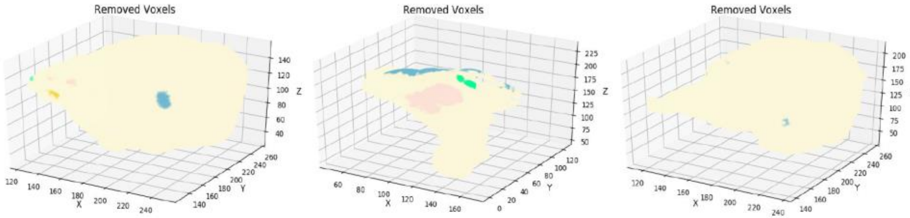
Experiment

- **Goal**: Perform an initial validation of the system and the recorded data
- **Participants**: 7 participants including 3 attending surgeons 3 residents and 1 medical student
- **Methods**: Operate on multiple anatomies
- **Results**:
  1. Temporal, kinematic and dynamics data for each participant



(a) (b) (c)

  2. Visualization of volume removed



P1 P2 P5

Critical Review

- **Pros**:
  - The author does a good job at integrating hardware and software of the system
  - FIVRS provides a realistic “simulation system” for skull-surgery
  - And it offers an extensive data generation and recording interface using an industry standard format
- **Cons**:
  - Small sample size and limited diversity
- **Key takeaway**:
  - Improvements on visual fidelity
  - User-friendly interfaces and interaction
  - Clear data management

Conclusion

- The framework established by the paper is applicable to our project
- The simulation of virtual drilling can be an effective tool for surgical training and planning

Reference

[1] Munawar, A., Li, Z., Nagururu, N., Trakimas, D., Kazanzides, P., Taylor, R. H., & Creighton, F. X. (2023). Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond. *arXiv preprint arXiv:2302.13878*.

[2] Munawar, A., Li, Z., Kunjam, P., Nagururu, N., Ding, A. S., Kazanzides, P., ... & Unberath, M. (2022). Virtual reality for synergistic surgical training and data generation. *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, *10*(4), 366-374.

Johns Hopkins
Whiting School of Engineering

THANKS