JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Background Reading Presentation1: Simulation Assisted Navigation for Skull-base Surgery

Group 13: Xinhao Chen, Zhaomeng Zhang

Mentors: Dr. Adnan Munawar, Dr. Manish Sahu, Max Li, Mohammad Salehizadeh, Dr. Peter Kazanzides, Dr. Pete Creighton, Dr. Danielle Trakimas, Dr. Deepa Galaiya, Dr. Russ Taylor

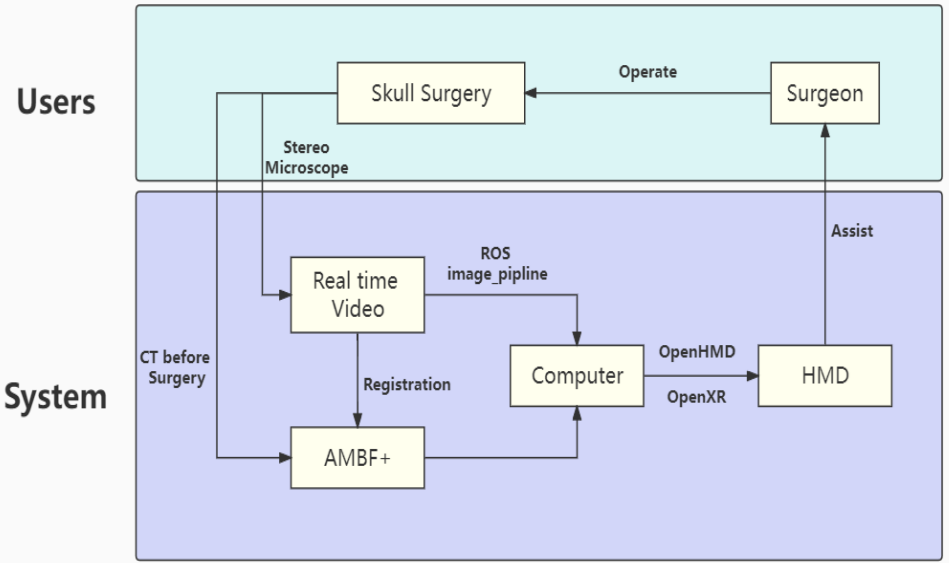
Project Summary

Problems of skull base surgery:

- Different anatomy of patients [2].
- Delicate and complex surgical procedures [4].

Goals:

- Provide immersive, detailed, and real-time navigation for surgeons.
- Develop a pipeline for augmenting stereo microscopic video with AMBF simulation.



[2] Cousins, V.: Lateral skull base surgery: a complicated pursuit? The Journal of Laryngology & Otology 122(3), 221–229 (2008)
[4] Munawar, A., Li, Z., Kunjam, P., Nagururu, N., Ding, A.S., Kazanzides, P., Looi, T., Creighton, F.X., Taylor, R.H., Unberath, M.: Virtual Reality for Synergistic Surgical Training and Data Generation. Comp. Meth. in Biomech. and Biomed. Eng.: Imaging & Visualization (2021)

The First Paper

Title: Virtual Reality for Synergistic Surgical Training and Data Generation

Author: Adnan Munawar , Zhaoshuo Li , Punit Kunjam, Nimesh Nagururu, Andy S. Ding , Peter Kazanzides, Thomas Looi, Francis X. Creighton , Russell H. Taylor and Mathias Unberath

Time: AE-CAI (Augmented Environments for Computer Assisted Interventions), November 2021

Key Content:

- AMBF+ application: virtual drilling simulator for skull base surgery
- AMBF+ system description
- Data generation and recording from AMBF+ simulation
- Evaluation on data quality for computer vision and deep learning algorithm development

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The Second Paper

Title: Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond

Author: Adnan Munawar , Zhaoshuo Li , Nimesh Nagururu, Danielle Trakimas, Peter Kazanzides, Russell H. Taylor and Francis X. Creighton

Time: IPCAI (Information Processing in Computer-Assisted Interventions), June 2023

Key Content:

- Introduction of Fully Immersive Virtual Reality System(FIVRS) for Skull base Surgery
- Detailed user interaction and interfaces of FIVRS
- FIVRS data generation and management
- Results of user study

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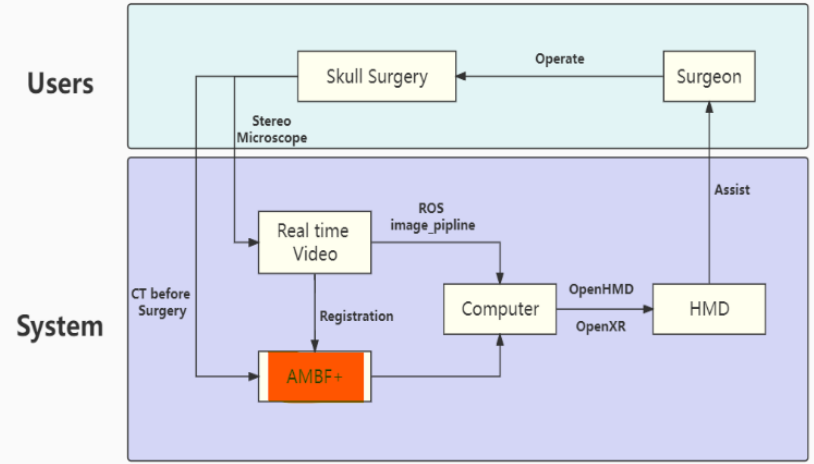
Relevance

Virtual Reality for Synergistic Surgical Training and Data Generation (2021, Munawar)

Introducing AMBF+ system application on skull base surgery from software perspective: AMBF simulation in HMD, some parts of registration

Both paper work on immersive system of skull base surgery on top of AMBF



Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond (2023, Munawar)

Improving user experience from both hardware and software perspective: current stage, improve visual fidelity, GUI design.

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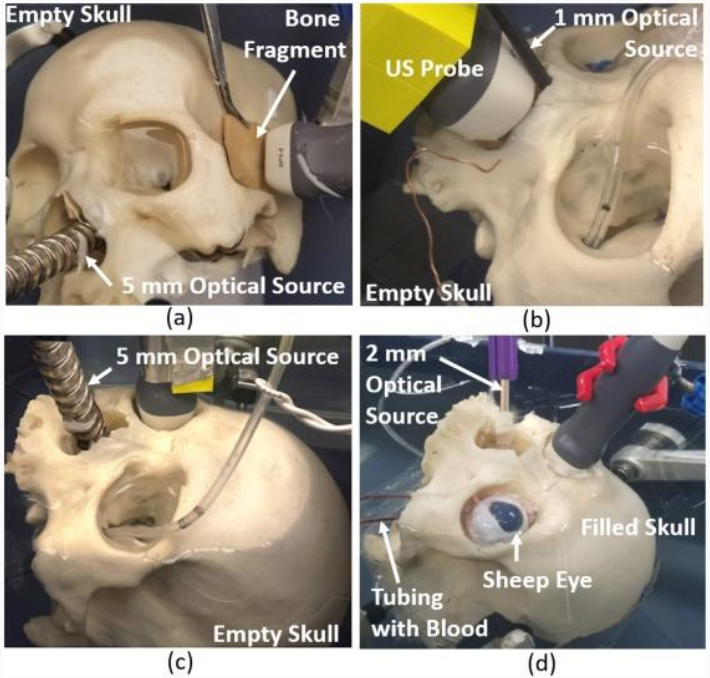
Background

Problem in skull base surgery:

- Cadaver heads: consumable and difficult to obtain [1].
- Anatomical phantoms are alternative but are expensive and consumable [1].
- Structured data: developing algorithms for image-guided computer-assisted surgical interventions [4].



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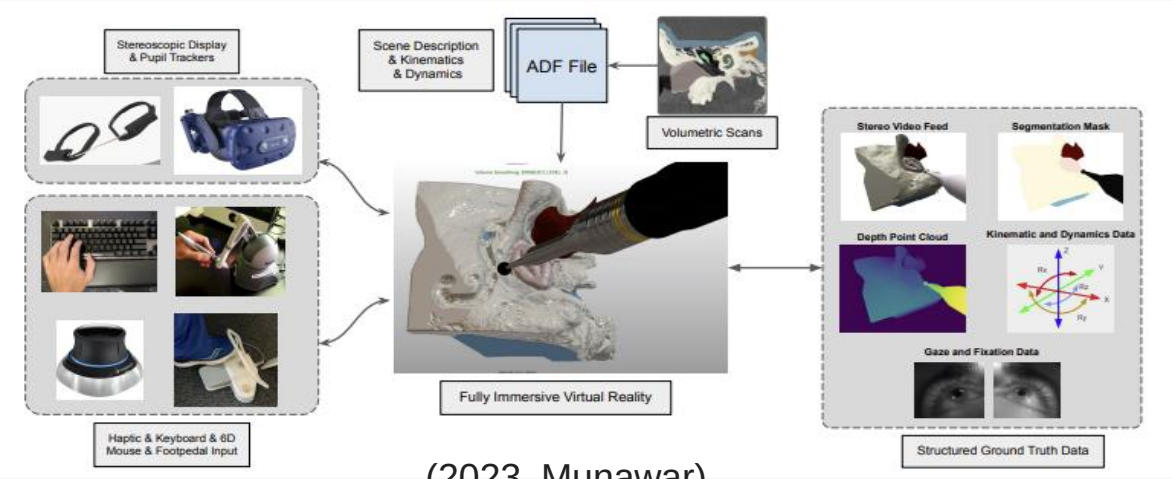
Technical approach

Fully Immersive Virtual Reality System Overview (FIVRS) [1]:

- Input devices
- AMBF simulator
- Generated data (Output)



(2023, Munawar)

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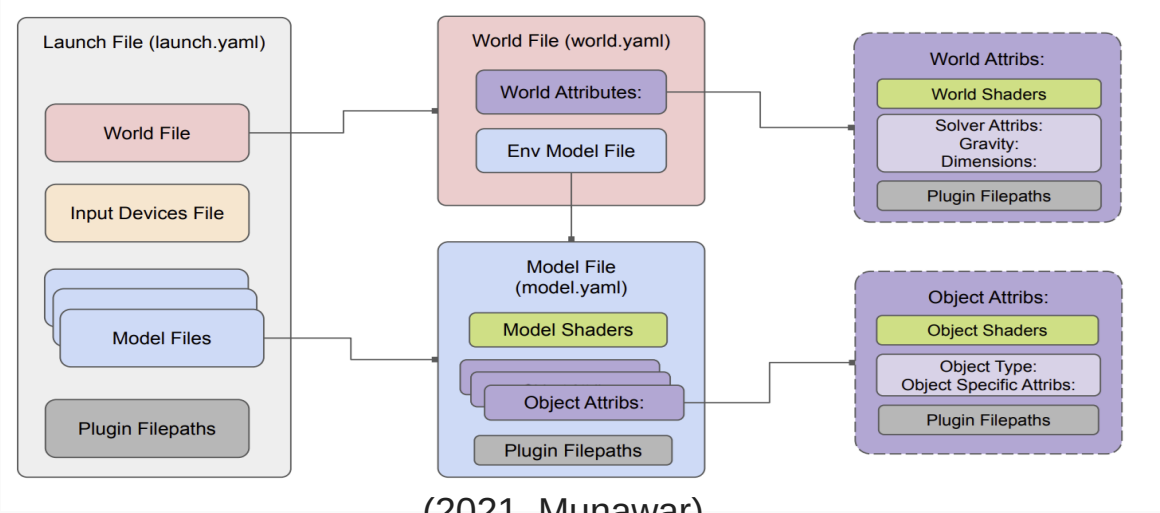
Technical approach

- Extended the rendering pipeline and AMBF Description Format (ADF) [4]
- ADF Files: are modular such that a model (consisting of bodies, joints, sensors and actuators) [4]
- Modular plugin handling interface: custom application development [4].



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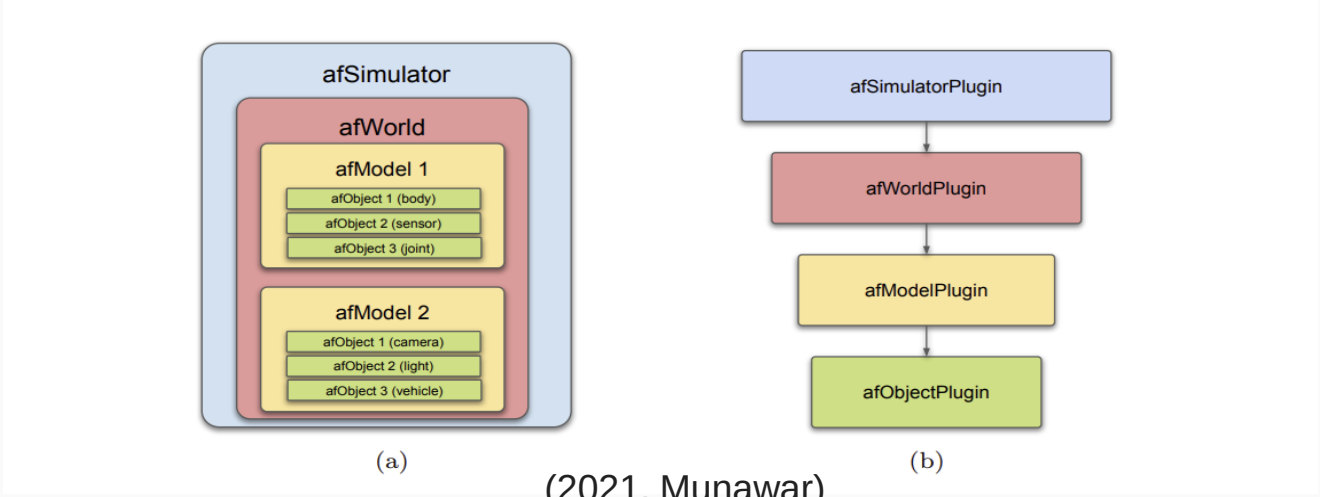
Technical approach

AMBF Plugin Design (hierarchical computational scope) [4]:

- Outer block: higher scope in hierarchy
- Higher scope: access more resources
- Launch file incorporated with plugin specification



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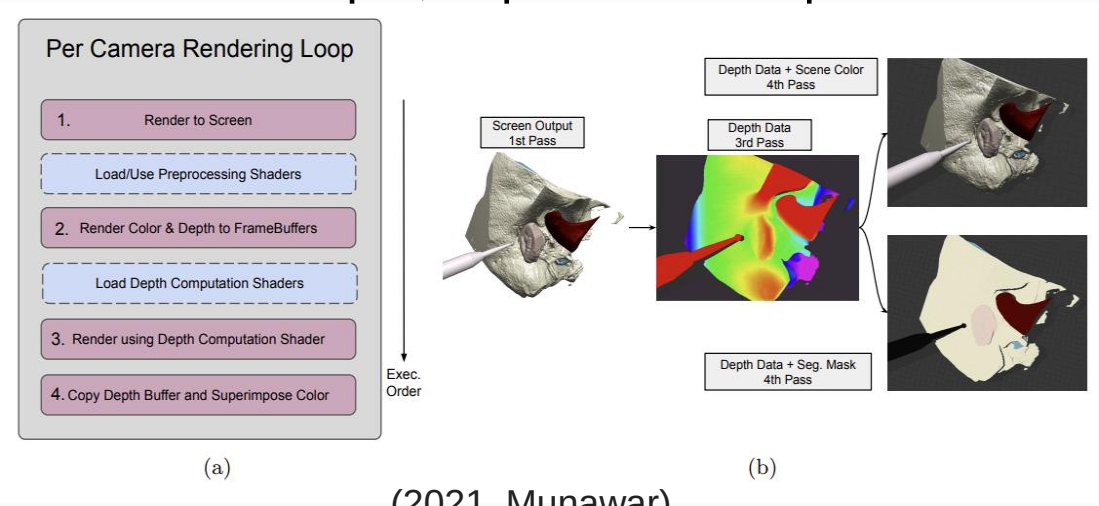
Technical approach

AMBF rendering pipeline for segmentation mask generation [4]:

- 2D color image
- Render color and depth
- Depth linearization and normalization
- Rescales normalized depth; Imposes on the point clouds



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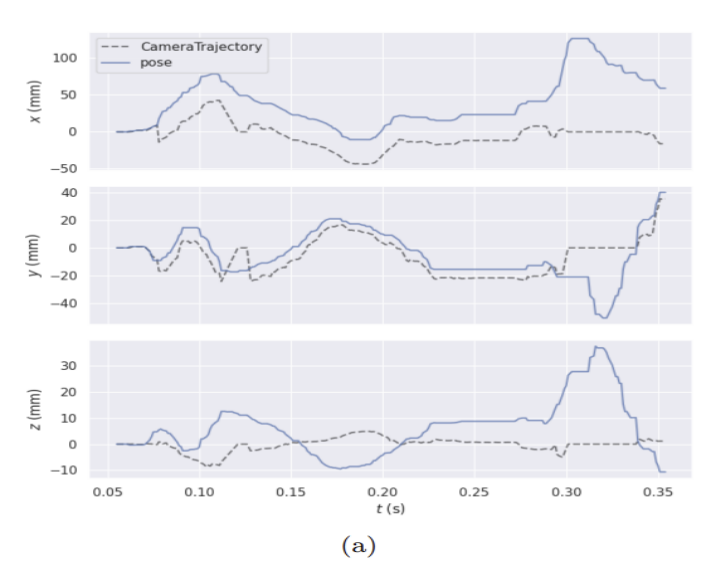
Experiment

About:
Evaluate the vision-based pose tracking, ORB SLAM V3 extracts features from stereo images (simulation) for computing camera pose relative to patient's anatomy [4].

Analysis:
In two settings, algorithm is robust on drilling, but errors increase with camera motion [4].

Summary:
The analysis with data generated from simulation can serve as complement to analysis using real images [4].



(a)

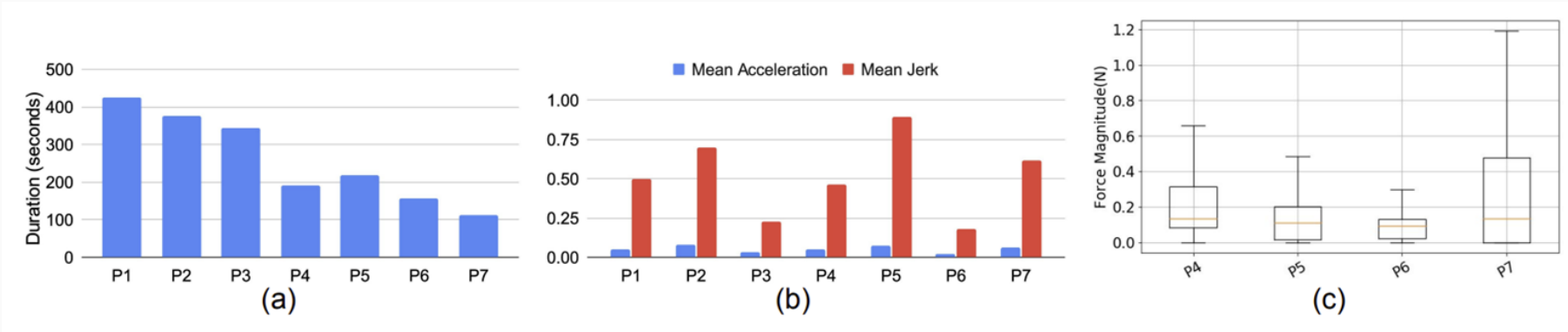
	Translation Error (mm)	Rotation Error (deg)
Moving camera	40.97 ± 22.40	8.44 ± 3.07
Moving drill	8.1E-1 ± 9.1E-1	3.2E-3 ± 3.6E-3

(2021, Munawar)

[4] Munawar, A., Li, Z., Kunjam, P., Nagururu, N., Ding, A.S., Kazanzides, P., Looi, T., Creighton, F.X., Taylor, R.H., Unberath, M.: Virtual Reality for Synergistic Surgical Training and Data Generation. Comp. Meth. in Biomech. and Biomed. Eng.: Imaging & Visualization (2021)

User Study

- About: Conduct a pilot study with 7 participants(3 surgeons, 3 residents, 1 student) to perform cortical mastoidectomy on a FIVRS setup for the system initial validation [1].
- Results: only show the utility of the system and the recorded data (temporal, kinematic, and dynamics) [1].
- Summary: Feedback from user about visual fidelity 1) unnatural facts/edges on the anatomy 2) difficulty in perceiving depth 3) mediocre illumination [1]



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Critical Review

Pros:

- paper clearly describes the functionality of fully immersive virtual reality system for skull base surgery.
- They conducted experiments and user study for validating and improving the system.

Cons:

- The paper can provide more information about user study.

Future work:

- Improve visual fidelity
- Complete the surgical assessment for training surgeons.
- Extend new functionality, like provide real-time navigation for skull base surgery

Paper—Twin-S: A Digital Twin for Skull-base Surgery

- Title:

  Twin-S: A Digital Twin for Skull-base Surgery

- Authors:

  Hongchao Shu, Ruixing Liang, Zhaoshuo Li, Anna Goodridge, Xiangyu Zhang, Hao Ding, Nimesh Nagururu, Manish Sahu, Francis X. Creighton, Russell H.Taylor, Adnan Munawar and Mathias Unberath

- Venue:

  Information Processing in Computer-Assisted Interventions (IPCAI), June 2023

- Key points:
  1. Present Twin-S, a digital twin framework for skull base surgery.
  2. Analyze the performance of Twin-S
  3. Illustrate a use case of Twin-S

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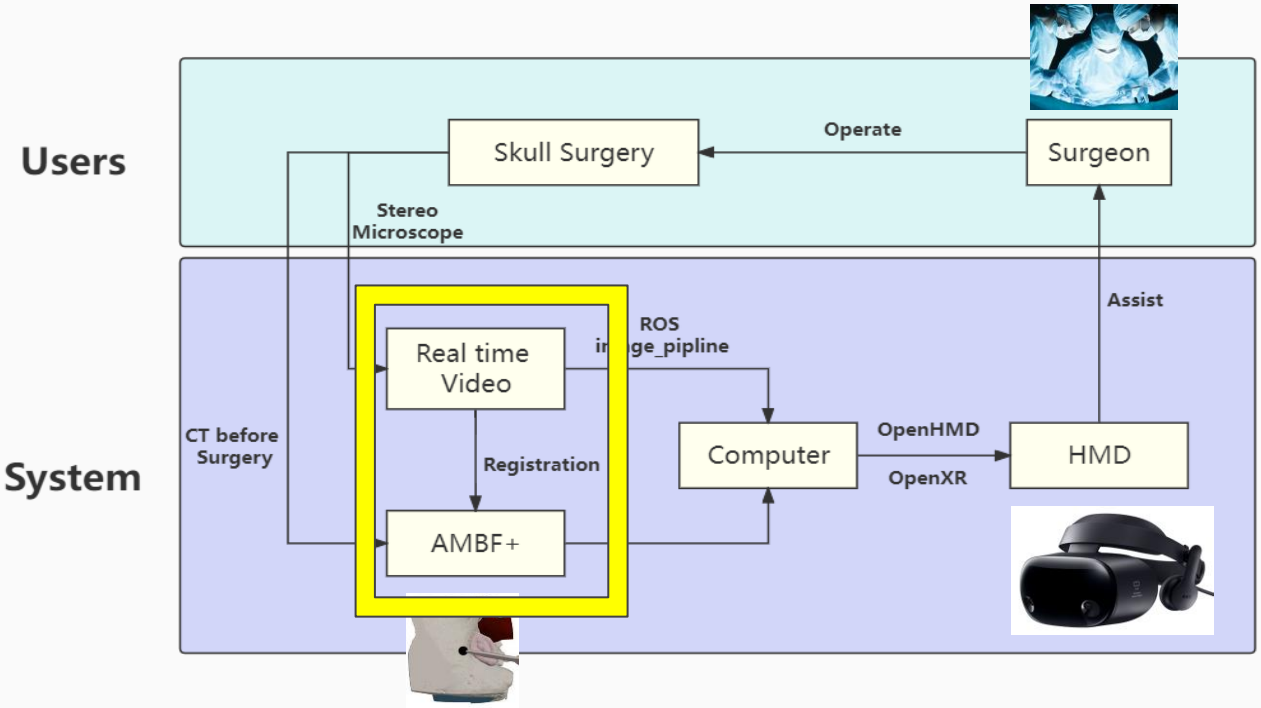
Relevance



What does this paper give us?

- A reliable method for registration
- Evaluations for the performance

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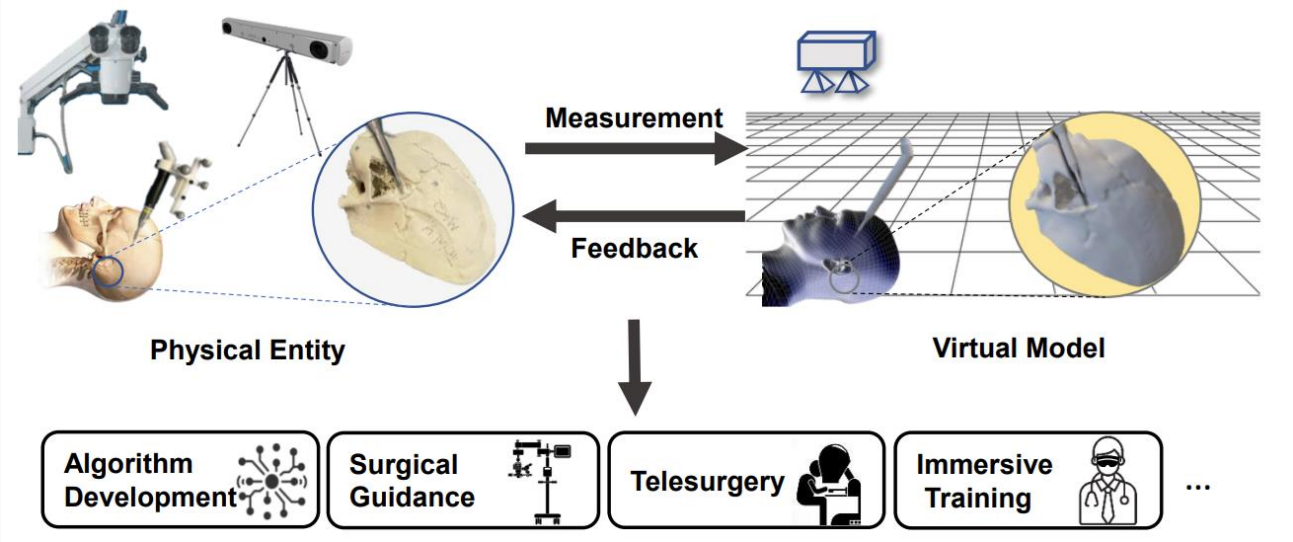
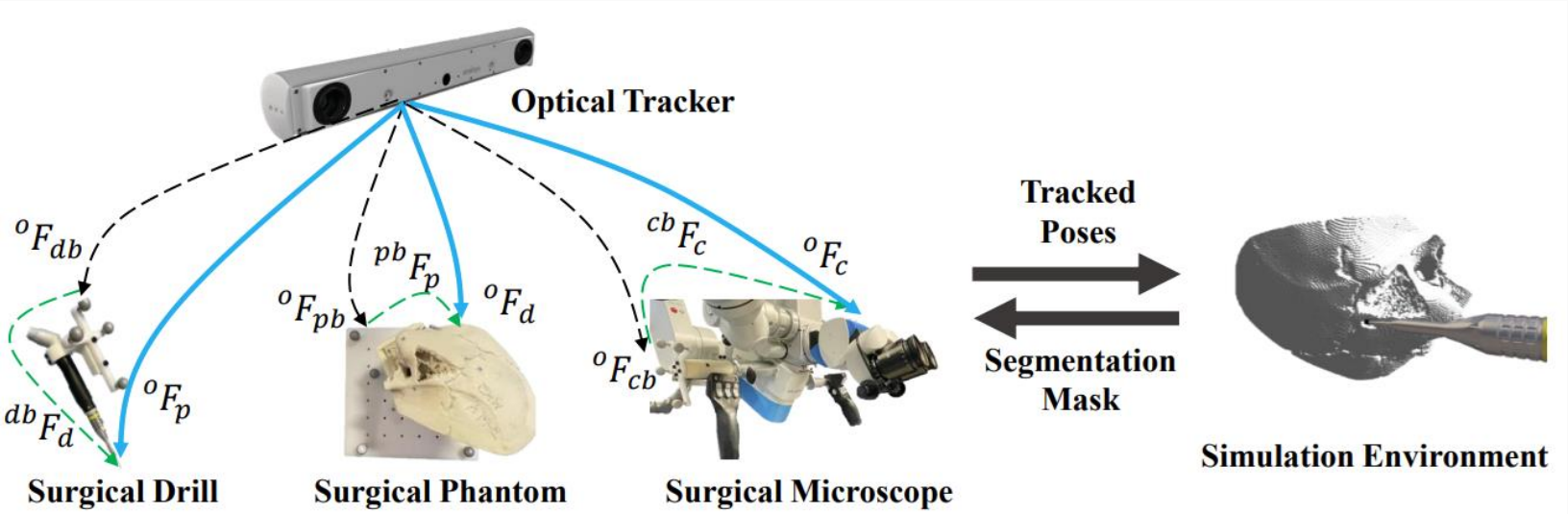
Background

- Digital twins are virtual counterparts of real-world processes
- They are widely used in biomedical sciences.



Twin-S models and tracks the critical components of skull-base surgery.

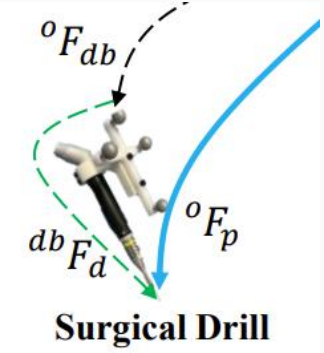
Technical approach: Overview



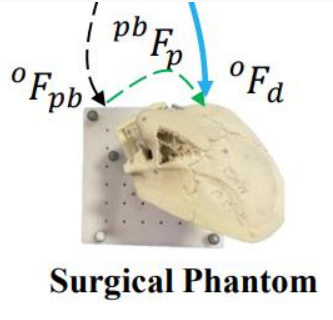
Overview of Twin-S for skull-base surgery

Technical approach: Modeling

- Surgical Drill
  - Mount the optical tracking markers at the tail
  - Rotation part only needs 2 DoF
  - Align the drill shaft with the Z-axis of the robot to find shaft axis



- Surgical Phantom
  - Mount the phantom on a board with optical tracking markers
  - Sample 380 points on the physical phantom surface using a tracked pointer tool



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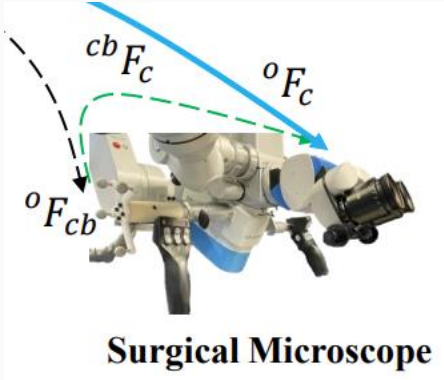
Technical approach: Modeling

- Tool-to-tissue Interaction
  - Approximate the drill tip as a sphere
  - Voxels that collide with the drill tip sphere are removed

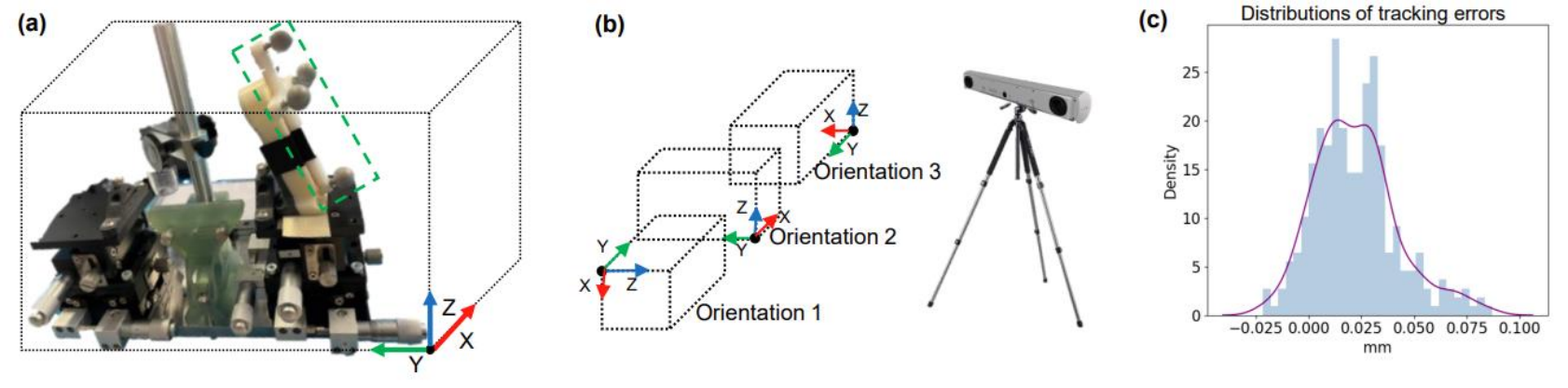
- Surgical Microscope
  - Optical tracking markers are mounted on the handle of the camera
  - Do hand-eye calibration to obtain the transformation between camera and eye lens.[5]



[5] Furrer, F., Fehr, M., Novkovic, T., Sommer, H., Gilitschenski, I., Siegwart, R.: Evaluation of Combined Time-Offset Estimation and Hand-Eye Calibration on Robotic Datasets. In: Field and Service Robotics, (2018)

Experiment

- **Optical Tracking Accuracy Experiment**



- **Results:** Mean error is 0.02 mm, with a standard deviation of 0.02 mm and a maximum error of 0.08 mm.
- **Summary:** The sub-millimeter accuracy of the optical tracker is sufficient for the purpose.

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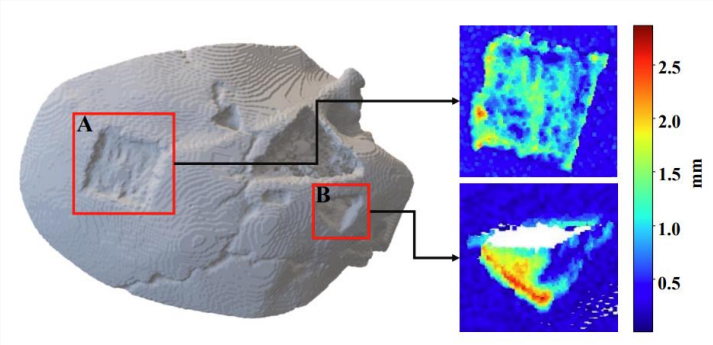
Experiment

- **Camera Calibration Accuracy Experiment**
- **Results:** Mean re-projection error (RPE) is 16 pixels, i.e. 1.9 mm.

- **Drilling Simulation Accuracy Experiment**
- **Results:** Average error of drilled regions is 1.39 mm with a standard deviation of 0.62 mm. Error do not related with drilling depth.



- **Summary:** Twin-S can update the anatomical model with a precision comparable to conventional optical navigation systems.

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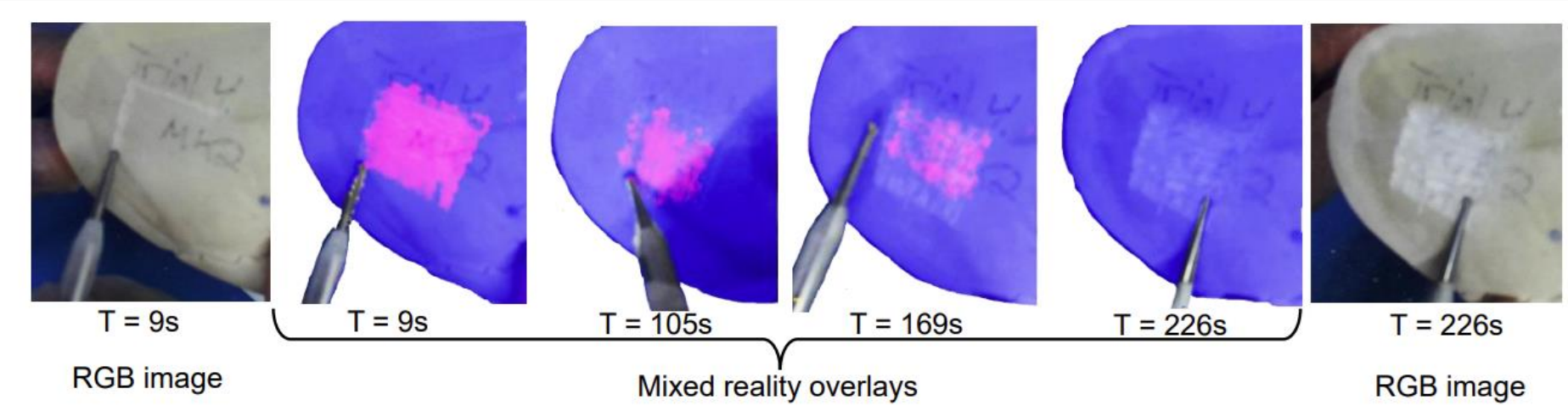
Experiment

- **Computation Evaluation Experiment**

Time proportions of Twin-S	Mean computational time (ms)
Data synchronization	20.5
Pose update	0.2
Simulator volume rendering	12
Collision simulation	3
Overall execution time	**35.7**

- **Results:** The overall run time of Twin-S is 35.7 ms (28 FPS) with Nvidia 3060 Laptop Graphic card and Intel i5 CPU.
- **Summary:** Fast enough

Use Case



Offer depth information that may be difficult for surgeons to observe due to bone dust, blood, and etc.

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Critical Review

- **Pros**
  - Successfully build a twin system with high accuracy and short execution time
  - Contain comprehensive evaluations to the system
- **Cons**
  - Only have a simple use case
- **Future work**
  - Optimize the spatial arrangement of the optical tracking markers to expand evaluation in deeper regions
  - Integrate vision-based tracking algorithms to further improve the accuracy
  - Conduct more studies to evaluate the system
  - Demonstrate the application of Twin-S in dataset generation
  - Build a fully functional mixed reality system with more effective graphics interfaces

Reference

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

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Thank You