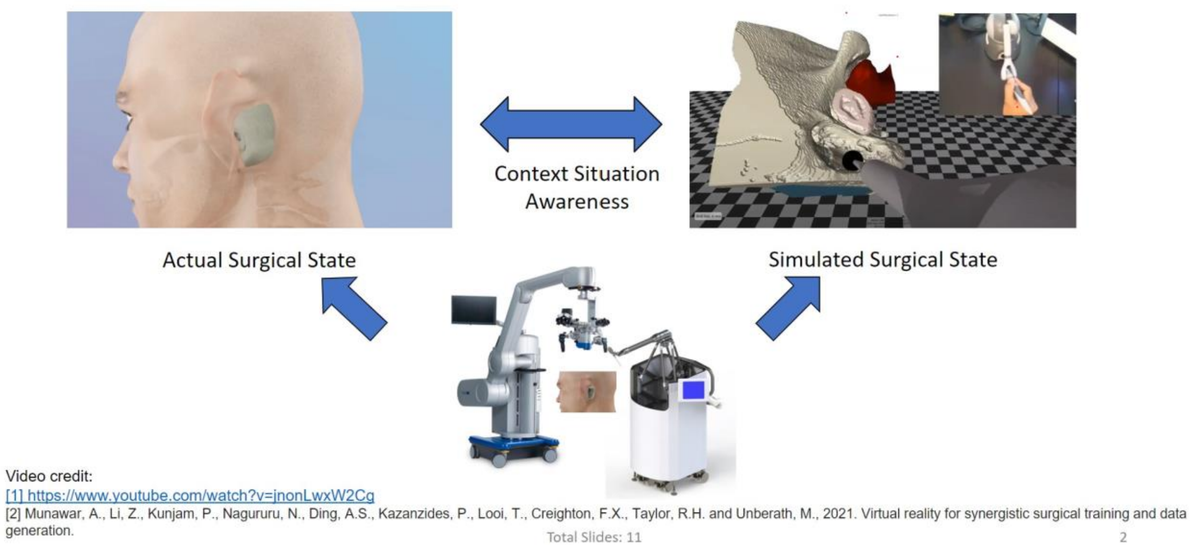
VR-Guided Skull Base Surgery Proposal

Topic and Goal

Topic

Mastoidectomy is a surgery conducted on the patient's skull-base behind the ear. A key part of this surgery is that the surgeon will drill out a part of the bone to reach the inner ear. This is a challenging procedure because the tissue near the inner ear area is complex and has a dense distribution. Surgical robots can be effectively used in this space to guide the surgeon through the drilling process and to minimize the likelihood of error. Feedback can be provided to the surgeon through a virtual visualization of the surgical space, and through force and haptics applied directly to the surgeon. In order to provide these feedback and constraints to assist the surgeon, the robot needs to know the context of the surgical space and send and receive state and constraint information to and from the simulator and a possible higher-level controller. We seek to combine the virtual and actual surgical states to achieve context situational awareness during surgery.



Goal

Our project goals are to create a virtual environment in the Asynchronous Multi-Body Framework (AMBF) simulation environment, and to synchronize the movements between the surgical robots in the virtual and actual states. The surgical robot we will be interfacing with is the Galen Robotics System, which is a cooperative surgical assistant used to guide the surgeon in minimally invasive surgery in the ENT space. In order to achieve our first goal, we will need to include at least the Galen Robot, an attached surgical drill, and the skull-base model in the simulated environment, and provide various visual feedback, scaling, and camera angles. In order to achieve our second goal, we will need to first establish a mode of communication between the robot and the AMBF simulation. Then we will need to develop a control scheme to keep them both in sync with each other. This means movements in the physical robot will need to be mapped to the virtual space, and movement and constraints in the virtual space will need to be reflected in the physical robot.

Team Members and Mentors

Team Members

Tianyue (Tommy) Liang, Hongyi (Mike) Fan, Jintan Zhang

Mentors

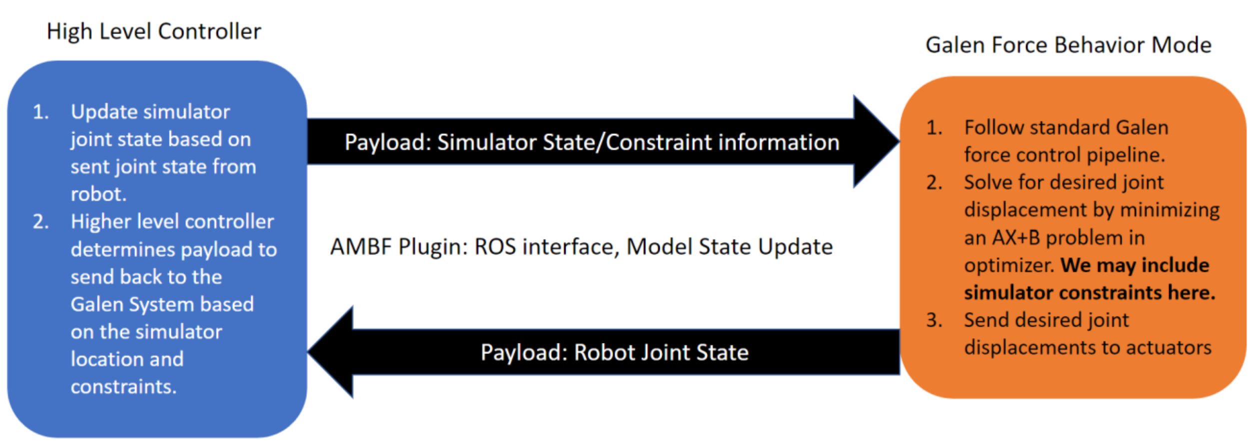
Max Li, Dr. Adnan Munawar, Dr. Francis Creighton, Professor Mathias Unberath, Professor Russell Taylor

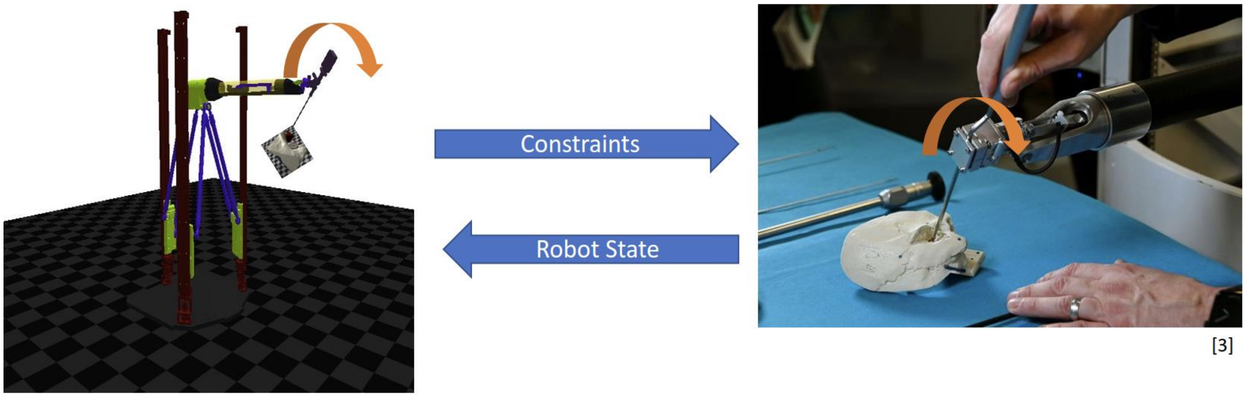
Relevance

For the specific surgical space that we are targeting with this project, this is important due to the challenging nature of performing surgical drilling during a mastoidectomy. As mentioned earlier, the drilling space is congested, full of densely distributed tissue, many of which are sensitive. The combined system of virtual and actual surgical spaces that we seek to develop provides the surgeon with a myriad of feedback, hopefully improving the accuracy of the surgical procedure. In a wider context, this solution sets a precedence for information-enhanced surgery in the cooperative robotics surgical space and serves as a platform for future development of virtual and physical feedback that can be provided to a surgeon during complicated surgical procedures.

Technical Approach

As mentioned earlier, our overarching objectives are to develop a virtual scene in a simulator that combines the Galen Surgical System with the drill and skull base, and to develop a control scheme to facilitate communication between the Galen Robotics system and the simulator. The virtual scene will be developed in the AMBF simulator, and plugins will be used to send and receive information to and from the Galen Robotics System. Registration will be assumed to be fixed for this. Joint state information will be sent from the Galen side to the simulator side, and a high-level controller on the simulator side will determine the necessary constraint information from the simulator to send to the Galen side. The Galen force behavior mode will then resolve these constraints, either as a pseudo-force, or as a parameter in the optimizer. Diagrams depicting this communication pipeline is shown below:





Deliverables

Minimum Deliverable:

Working Software and Documentation for VR - robot communication, including controls to keep physical robot in sync with the virtual robot; and AMBF simulation environment with all relevant components.

Expected Deliverable:

Interfaces developed for ease of integration with registration and SDF teams. Additional UI components or scripts for updating settings/modes to improve usability.

Maximum Deliverable:

Internal user study of the surgical system. Potentially conference paper.

Key dates and Assigned Responsibilities

Project Timeline

#Week 1-3	4	5	6	7	8	9	10	11	12	13	14	15-16
Preparation	Presentation											
	Simulation follows robot											
		Robot gets feedback from simulation										
			Add "Volumetric Drilling" to Galen World	Finetune Robot mesh models in virtual world								
				Assemble and test combined virtu al environment	Testing synced Robot and simulation							
						VR Support						
							Interface for combining other groups' work					
							Usability improvement					
								Working towards maximum deliverables				Final Report Final Presentation

Preliminary works including project presentation done by end of Week 4. We plan to have the virtual robot in the simulation to follow the movement of the actual robot by Week 5. After that, we plan to have the robot receive feedback from the simulator buy Week6 and integrate two virtual worlds into one -- which will be our basic prototype software -- by Week 7.

Testing and usability improvement will be done from Week 8 towards the end of the course. It includes testing functions, debugging, UI (User Interface) implementation, VR (Virtual Reality) support, and integration of other teams' work, etc.

Depending on the permission of team members' workload and the progress of the project, we will start working toward our maximum deliverable (Internal user study, conference paper, etc.) by Week 11.

Assigned Responsibilities

Tommy Liang:

> Develop new simulator control mode on the Galen side that can receive and resolve constraints sent by the high-level controller.

Jintan Zhang:

> Develop communication scheme that can send and receive information to and from the Galen System, keeping the virtual space synchronized with the actual space.

HongYi(Mike) Fan:

> Integrate the volumetric drilling simulator and the Galen robot simulator. Fine tune the Galen Robot mesh model.

Dependencies and Plan for Resolving

Galen Surgical System:

> Available at the "mockOR" laboratory. Access to the Galen Surgical System at the "mockOR" laboratory can be requested online. Failure to access the Gelen Surgical system on time can set the timeline back. To avoid this, we will schedule ahead of time for access to the Galen System. The team will contact Galen Robotics, Inc. If we meet technical difficulties with the Galen System.

Surgical Drill:

> Available at the "mockOR" laboratory. We can access the surgical drill during sessions at the "mockOR" laboratory. Dimensions of the drill are essential for the simulator to produce accurate results. Failure to access the surgical drill can set the timeline back or result in inaccurate simulation setup. The team will coordinate the schedule to ensure availability of the surgical drill during sessions at the "mockOR" laboratory.

Desktop and Monitors:

> Available at the "mockOR" laboratory. We can access the desktop during sessions at the "mockOR" laboratory. Failure to gain access to the desktop computers may set the timeline back. The team will coordinate the schedule to ensure availability of the desktop computer

during sessions at the “mockOR” laboratory. If we fail to get access to the desktop machines at the laboratory, the team will prioritize tasks that are independent of the Galen Surgical System.

HTC Vive:

Available at the “mockOR” laboratory. Failure to gain access to the VR headset may set the timeline back for VR support objective. The team will schedule ahead of time to ensure the availability of the VR headset during sessions at the “mockOR” laboratory. Additional VR headset can be requested from the mentors.

C++, Python, OpenGL, ROS, ambf:

Open source. Failure to utilize software tools may set the timeline back or produce extra work. If the team meets technical difficulties regarding the usage of framework/software tools, we will contact mentors for help or research open-source documentations.

Mentor Availability:

Scheduled routine meetings with Mentors. Failure to receive sufficient feedback or technical help from the mentors can set the timeline back and impact the quality of the project. The team will maintain weekly scheduled meetings, and request additional discussions to ensure sufficient feedback from the mentors.

Management Plan

Team Communication

General team communications are via the Slack channel. Weekly meetings via Zoom or in-person at the “mockOR” Laboratory. Urgent messages or discussions are via Zoom online meetings or in-person meetings at any time.

Communication With Mentors

Weekly meetings with mentors on Friday at 4pm for progress report and feedback. Urgent messages or discussions are via Zoom online meetings or the Slack channel.

File Management

General files (documentations, papers, etc.) stored in the team OneDrive. Source code files, readme files, software resources are controlled in private GitHub repository.

Reading List

1. A. Munawar and G. S. Fischer, "An Asynchronous Multi-Body Simulation Framework for Real-Time Dynamics, Haptics and Learning with Application to Surgical Robots," 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2019, pp. 6268-6275, doi: 10.1109/IROS40897.2019.8968594.
2. Adnan Munawar, Zhaoshuo Li, Punit Kunjam, Nimesh Nagururu, Andy S. Ding, Peter Kazanzides, Thomas Looi, Francis X. Creighton, Russell H. Taylor & Mathias Unberath (2021) Virtual reality for synergistic surgical training and data generation, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, DOI: 10.1080/21681163.2021.1999331