EN 601.656 Computer Integrated Surgery II
Project Proposal

Simulation Assisted Navigation for Skull Base Surgery

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1. Introduction

In minimally invasive skull base surgery, surgeons normally relay on their experience with support of endoscope and microscope to do the operation [6]. Due to the lack of stereo anatomy model of patients and real-time detailed navigation information, the skull base surgery is considered as a difficult operation for many surgeons. In order to solve the challenges in skull base surgery, we plan to develop a pipeline for augmenting stereo-microscope video with AMBF simulation for navigation during the operation. Our project is built upon prior works, like Asynchronous Multi-Body Framework (AMBF) [1] and a fully immersive virtual reality system (FIVRS) [3]. We also set a clear timeline and manage plan to support us finish all required tasks for this project.

2. Background and Motivation

The skull base surgery is a specialized operation closely related to neurosurgery and otolaryngology, which surgeons need to access the skull of a patient to treat the diseases [1]. Pituitary tumors, meningiomas, and chordomas are the diseases requiring skull base surgery [4]. In certain types of skull base surgery, the bony tissue must be removed by surgical tools in order to reach the target anatomy. However, it is a difficult and complicated procedure for surgeons for two reasons.

Patients usually have different anatomy structures in some surgical regions. For example, male patients usually have thicker and larger skull bones, but the skulls of females are generally thinner and lighter [6]. And male eye sockets are squarer than females [6]. The sex is only one factor that can make an individual's skull different from others. These distinct skull structures increase the difficulty of doing the operation for surgeons. Therefore, surgeons hope to have a stereo anatomy model of patients as reference during the surgery, which is one motivation for our project.

Moreover, the real-time and detailed navigation information could greatly assist the skull base surgery and lower the risk of operation [1]. During the operation, the surgical drills intend to remove the bony tissue rather than soft tissue, and if the soft tissue is beneath the bony tissue, surgeons are not able to see it, so they need to know how far soft tissue is located from the current position of surgical drill in real-time for making sure sensitive tissue won’t be hurt and damaged. To provide concrete and real-time operation navigation information for surgeons is the second motivation for our project.

3. Prior Work

A fully immersive virtual reality system (FIVRS) has been developed and designed for practice of skull base surgery. The system works on the fundament of Asynchronous Multi-Body Framework (AMBF) which is "an open-source 3D versatile simulator for robots and provides a real-time dynamic simulation of multi-bodies such as robots, free bodies, and multi-link puzzles." [5] Based on AMBF, our mentors developed FIVRS in recent years. To run the FIVRS requires a lunch file that consists of a world file, input device file, and model file. These three files are three types of AMBF Description Format (ADF) Files [1]. According to the Figure 1, the world file has env model file and world attributes that can be solver attributes, gravity, and dimensions. The env model file is formed by the model file which can be bodies, joints, sensors and actuators, and multiple model files can be loaded in the launch file [1]. The overall model loading flow for FIVRS is described in Figure 1.

Compared with AMBF, the rendering pipeline and AMBF Description Format (ADF) specifications are improved for AMBF+ [1]. Additionally, the modular plugin handling interface in AMBF+ allows users to do custom application development [1].

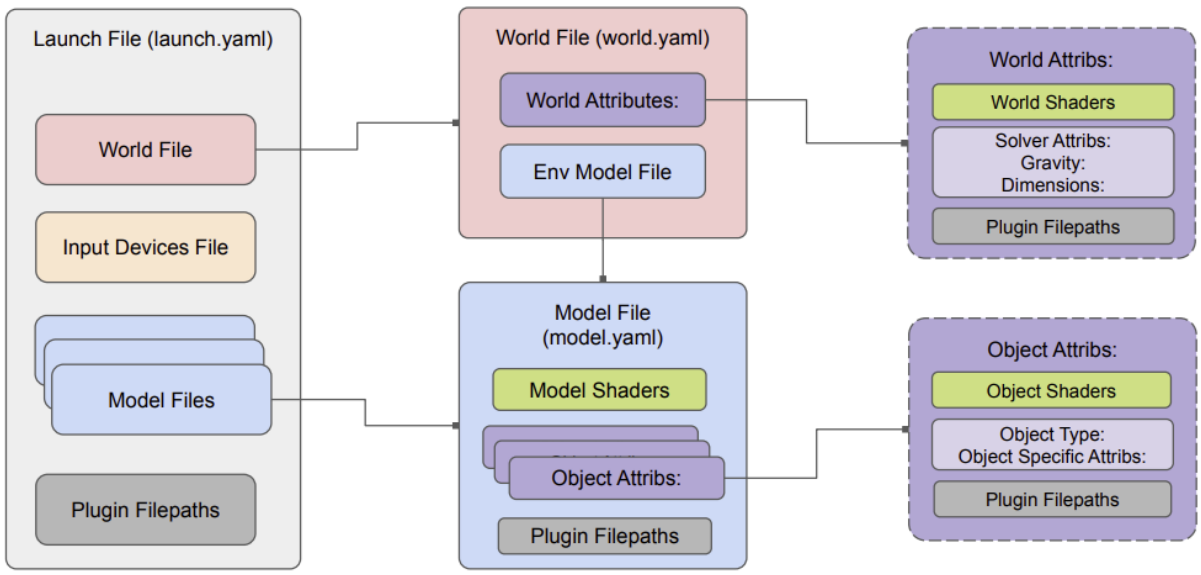

Figure 1: The overall model loading flow for AMBF+ [1]

Fully immersive virtual reality system allows users to load stereo anatomy models from actual Computer Tomography (CT) of patients and accepts various input devices, including stereoscopic display(VR headset), haptics device, keyboard, 6D mouse, and

foot pedal (Figure). With these input devices, surgeons can have an immersive stereoscopic view of anatomy and control the virtual drill to do the operation in the simulation environment. In the meanwhile, the system is able to generate valuable data for downstream algorithm development and surgical assessment of surgeons [1].

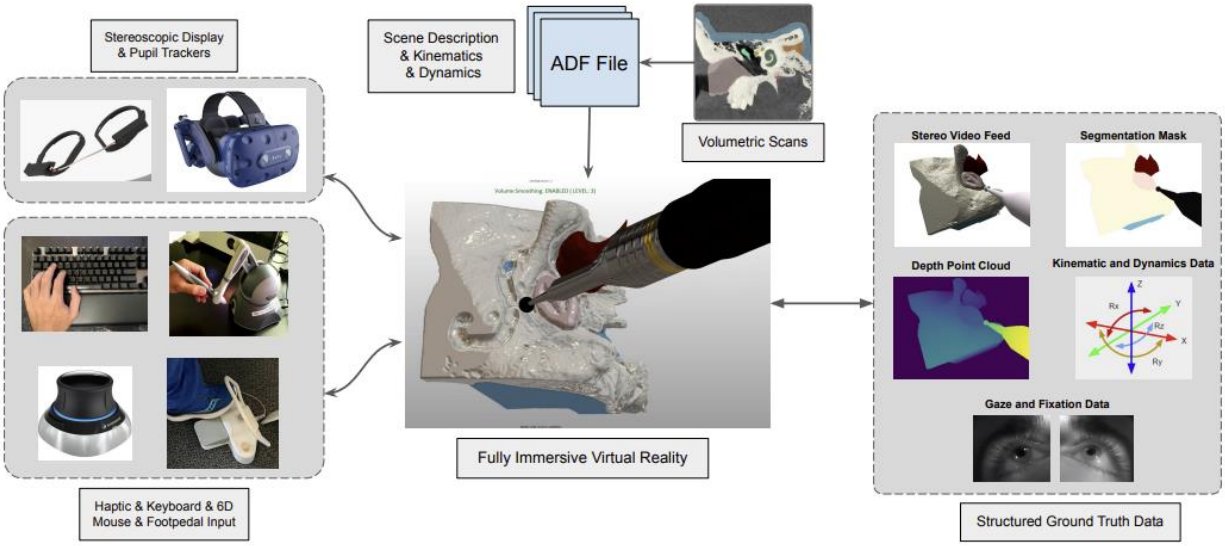

Figure 2: The fully immersive virtual reality system [3]

4. Goals & Deliverables

The project motivation and prior work drives us to develop a pipeline for augmenting stereo-microscope video with AMBF simulation for guidance in skull base surgery. In other words, the new system as much as possible to achieve that simulated operation simultaneously corresponds with real skull base surgery and provide guidance modalities to the surgeons to accomplish the surgery. Either real microscopic video and simulated stereoscopic view can be shown on VR headset to have an immersive view for surgeons. During the operation, they can pause the operation and load the simulated anatomy to get real-time and detailed surgical information. The view of the simulated anatomy also can be changed, like rotation, scaling, and slicing.

Based on these goals, we have several milestones:

1) Process the stereo microscopic video in the computer.
2) Display the video in HMD while operating.
3) Minimize the delay of showing video in HMD.
4) Integrate the video in HMD with AMBF.

5) Develop an user interface for the system.
6) Perform anatomy registration.
7) Update from the real operation to the simulation.
8) Conduct user study with surgeons.

The relationship between these milestones is that the former is the foundation for the latter except the fourth and fifth milestones. As a result, we need to do the fourth and fifth milestones simultaneously and finish other works one by one.

Our deliverables are follows:
Minimum: Develop the pipeline to augment stereo endoscopic video with the AMBF simulation in an HMD and conduct surveys for UI development.
Deliverables: A new version of the system which shows simulation & real video in HMD, User study report about UI design

Expected: Perform anatomy registration and update from the real setup to the simulation.
Deliverables: A new version of the system that can show real time simulation & real video in HMD

Maximum: Conduct user study with surgeons and present the system and findings in a paper.
Deliverables: User study report

5. Technical Approach

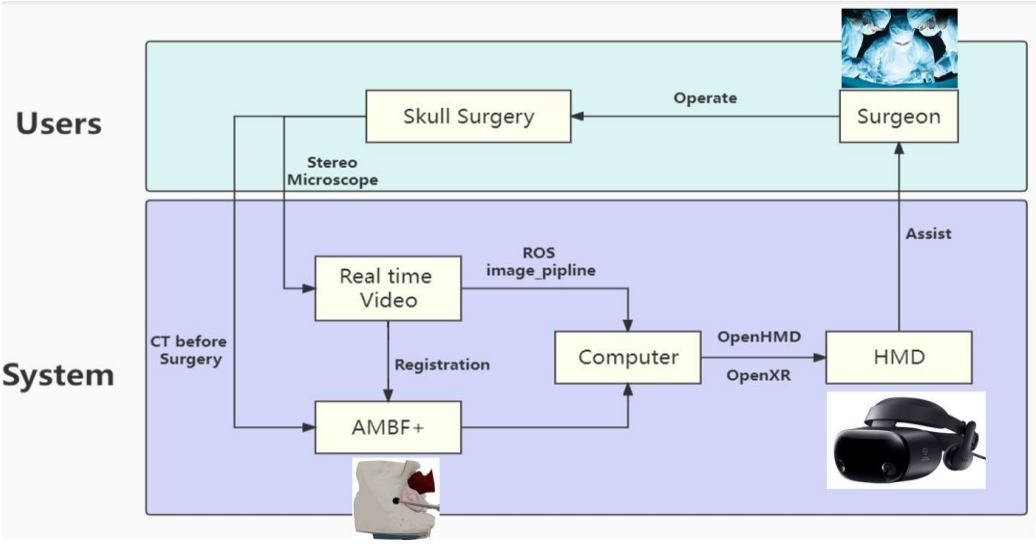

Figure 3: Workflow of the system

Figure 3 shows the workflow of our system. It can be divided into two parts, the users part and system part. As we mentioned in the motivation, skull base surgery is hard. The aim of our system is to assist surgeons by showing everything clearer.

We have a stereo microscope to produce real time video from surgery. We also have CT scan before surgery to construct the model in AMBF+. We already have ICP (Iterative Closest Point) registration through optical markers between real time video and simulation environments to connect them together.[2] This step enables the drill in AMBF+ to move and cut the same thing as the drill in real surgery. Then, we process both videos and transmit them to HMD. Surgeons can see both real time video and simulation video in HMD. They have many choices about simulation video. They can see the model from any point in any angle or see slices instead of 3D models.

Our task mainly focuses on the system part. We already have all the hardware and AMBF+ platform. The task we need to do is to connect all parts together and make them a whole system. We will start with the ROS Image pipeline to process videos. If its latency does not meet our specification, we may explore additional protocols and software such as Gstreamer. Image_pipeline fills the gap between getting raw images from a camera driver and higher-level vision processing.[10] It can process raw camera images into useful inputs to vision algorithms. Since AMBF+ also based on ROS, they can cooperate well.

We will use OpenXR & OpenHMD to display videos in HMD. OpenXR can simplify AR/VR software development and enable applications to reach a wider array of hardware platforms without having to port or re-write code.[11] OpenHMD can provide drivers for immersive technology, such as head mounted displays with built in head tracking.[12]

6. Testing Plan

We have two testing plans for our system. The first one is that we will test the whole system by ourselves on a model. For this test, we will focus on the latency time and error of registration in this system. The ideal result is that users cannot feel these errors. For example, it is hard to perceive a latency of 0.15 seconds in video.[13] But it is hard to achieve. So, the standard of passing this test is that errors should be small enough for surgeons to do the surgery. For example, if the latency is about 0.5 second, although users can feel that the system can still assist well. This testing plan is a part of expected goals.

The second testing plan is to conduct a survey and take feedback from surgeons. For this test, we will focus on finding out which video is displayed in HMD and how to display them. As introduced in the technical approach, surgeons have many choices about simulation videos. But we do not know which one is the most useful one when doing surgery. So, surgeons themselves will choose the video that can help. They can also choose how these videos are displayed. For example, a button can be used to shift different videos. Or one video is displayed while another one is displayed in a small window on the side.

7. Timeline and Dependencies

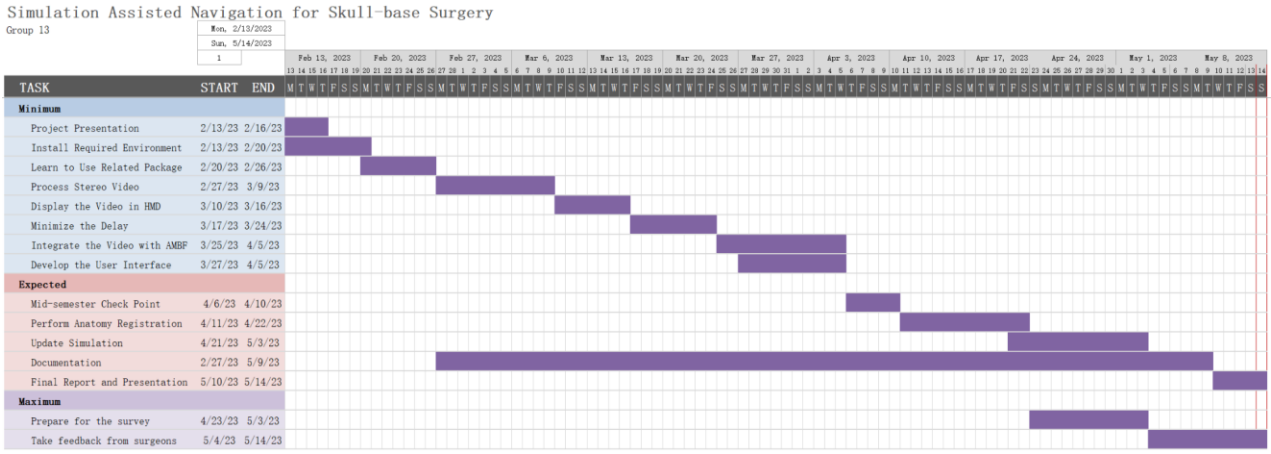

Figure 4: Gantt chart

Figure 4 is the Gantt chart for our timeline. We plan to finish minimum targets before the mid-term check point and finish expected & maximum targets before the final report. Documentation work will go through the whole process.

Our roles are that Xinhao Chen will display videos in HMD, minimize the delay and perform anatomy registration, while Zhaomeng Zhang will process, integrate video and update based on real operation. We will design UI and conduct surveys together. Table 1 shows our dependencies.

Dependency	Status	Contingency Plan	Planned DDL	Hard DDL
Install ROS on computer	Completed	Already Done	2/13/2023	2/13/2023
Install AMBF on computer	Completed	Already Done	2/13/2023	2/13/2023
Install OpenXR and OpenHDM on computer	On Going	Use computer in lab, or ask mentors for help.	2/20/2023	2/24/2023
Access to the Haag Streit microscope	On Going	Ask mentors for help.	2/20/2023	2/24/2023
Access to Mock OR	On Going	Ask mentors for help.	2/20/2023	2/24/2023
Access to VR devices	On Going	Ask mentors for help.	2/20/2023	2/24/2023
Hardware Check (HMD and Phantom Omni)	On Going	Try to fix them if fails ask mentors to buy a new one.	Continuous	Continuous

Table 1: The table of dependencies

8. Management Plan

We will have group meetings with Dr. Adnan and other mentors on every Wednesday at 2:30 pm in person. We will also meet with each other once every two days.
For communication and sending files, we use Microsoft Teams.

9. Reading List

- Virtual reality for synergistic surgical training and data generation [1]
- Twin-S: A Digital Twin for Skull-base Surgery [2]
- Fully immersive virtual reality system [3]
- Online document of ROS image_pipline, OpenHMD, and OpenXR [8] [9] [10]
- Calculating Stereo Pairs [7]

10.References

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