FINAL REPORT
TO IMPROVE THE CONTENT VALIDITY OF THE VIRTUAL DRILLING SIMULATOR
COMPUTER INTEGRATED SURGERY II
EN.601.656

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Group: fourteen

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Introduction:

Background:

Surgical simulators can assist surgeons in developing the surgical skills and spatial perception needed to operate without the risk of accidents occurring in actual patients. This project aimed to validate the audio feedback of the FIVRS (Fully Immersive Virtual Reality System) by finding relations between the force applied by the drill, drill audio, and the density of the material being drilled into.

Prior Work:

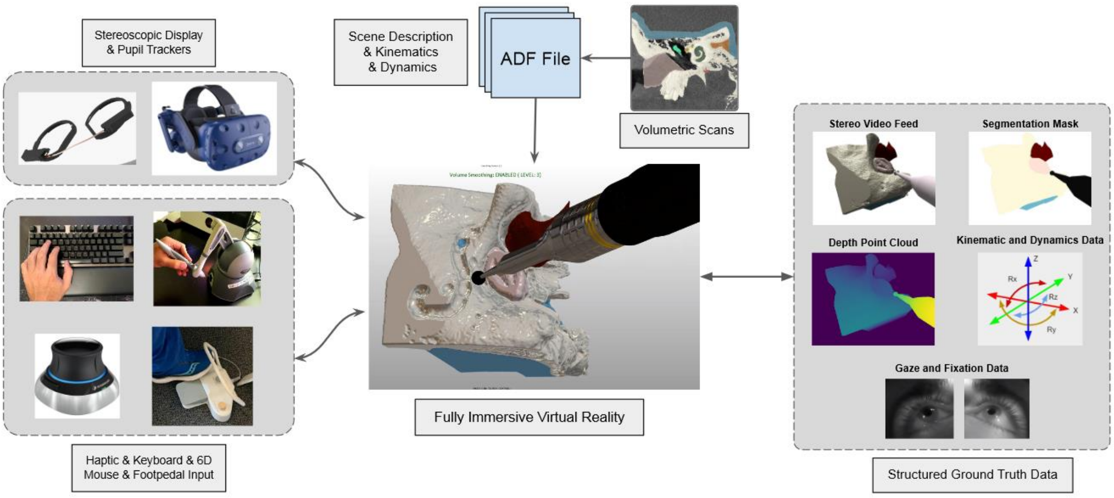

Figure 1: Fully Immersive Virtual Reality for Skull-base Surgery (Reference: (Munawar et al., 2023))

FIVRS or Fully Immersive Virtual Reality System was introduced in previous works related to this project. FIVRS combined high-fidelity surgical simulation software with a realistic hardware setup to provide a scalable and cost-effective alternative to cadaveric training for skull-base surgeries.

In the current FIVRS, the cutting force alters the pitch of the drill audio signal using the following equation:

$$p = A_{audio} - \parallel \vec{F}_{collision} \parallel / \vec{F}_{max}$$

where,

p : Signal's pitch.

A_{audio} : Custom maximum audio amplitude.

$\vec{F}_{collsion}$: Force generated from the collision detection algorithm.

$\vec{F}_{max}$: Maximum force thresholds for the haptic device.

Motivation:

Auditory displays can have immense potential in surgical simulators that aim at training skills associated with the correct interpretation of auditory information [1]. Plunging is a major hazard that occurs during drilling when the drill bit breaks through the far cortex of the bone. [2] Critical anatomy such as nerves and vessels can be damaged due to plunging.

The major clinical motivations for this project were:

1. Sound feedback can be utilized to minimize over-drilling problems [3] and reduce the risk of plunging into critical anatomy.
2. Validation of the FIVRS audio feedback will allow estimation of the accuracy and improvement of the current feedback system.

Goals:

This project aimed to extend the FIVRS simulator to supply more accurate audio feedback. Initially, this goal was broken down into the following four components:

1. Collection of two sound-force data sets.
2. Modeling report of the collected data set.
3. Implementation report of the function created.
4. Evaluation report of the functionality in the simulator.

However, not all components could be completed during the duration of this project. The deliverables were also changed when it was observed that data collection involved a lot more parameters than those originally thought of.

The final deliverables were as follows:

Minimum Deliverable:
Record and create a data set that contained sound during drilling, the density of the material being drilled into, and the force applied by the drill during drilling.

Expected Deliverable:
Modeling report of the data collected. *

Maximum Deliverable:
Implementation report of the functionality in the drilling simulator based on the modeled data.

The maximum deliverable could not be achieved within the duration of this semester.

[*: Indicates completion or partial completion of the deliverable within the timeline]

Technical Approach:

Phantom Design:

Three phantoms were used during the duration of this project. These phantoms were all cuboidal and filled with dental stone. For reference, bone density values were used. [4] The densities of the phantoms were selected as follows:

Phantom	Density (in kg/m^3)
Phantom 1 (LL)	1084.065
Phantom 2 (Avg)	1630.6
Phantom 3 (UL)	2100.3
Table 1: Density of the phantoms	

[LL – Lower Limit, Avg – Average, UL – Upper Limit]

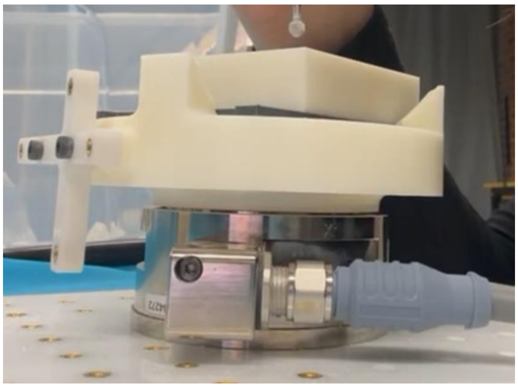

Figure 2: Phantom mounted on the gamma sensor.

Data Collection:

Drilling was done using the Galen Robot. All recordings consisted of a single stroke of about 3.5 cm along the surface of the phantom. The RPM (Revolutions per minute) of the drill was kept constant at 80,000. The orientation of the drill was kept constant during the entire motion of the drill. The angle of the drill with the phantom surface was kept below 90 degrees. The drill was first drilled into the surface of the phantom and then proceeded to move along the phantom surface in a straight line.

The data set consisted of a total of thirty recordings, ten on each phantom. Each reading had a rosbag and a wav file associated with it. More details about the data collection can be found in the data collection record linked on the project's wiki page.

Experimental Setup:

Lab Setup:

The audio file was recorded with a Logitech Yeti X microphone. The microphone was placed on a table along with the gamma sensor. The gamma sensor was mounted with the phantom and fixed with the help of four bolts. An Anspach force-sensing drill was fixed onto the Galen robot. The arm was moved such that the drill bit was positioned over the phantom.

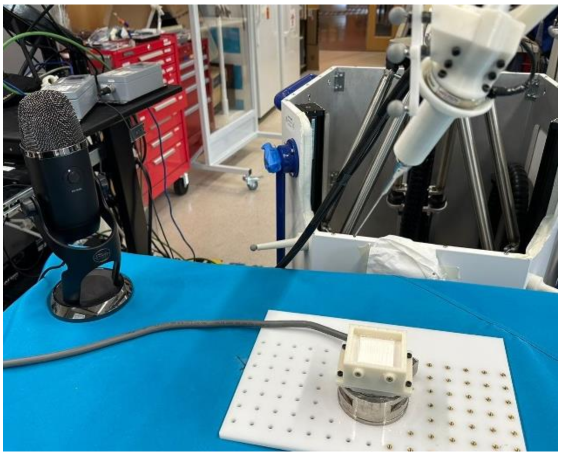

Figure 3: Experimental setup for data collection

Data Synchronization

During the recording, the phantom and the microphone were tapped manually before the drilling started. These taps were reflected as two spikes in both the audio and force data. The peak of the first spike was used to synchronize the data.

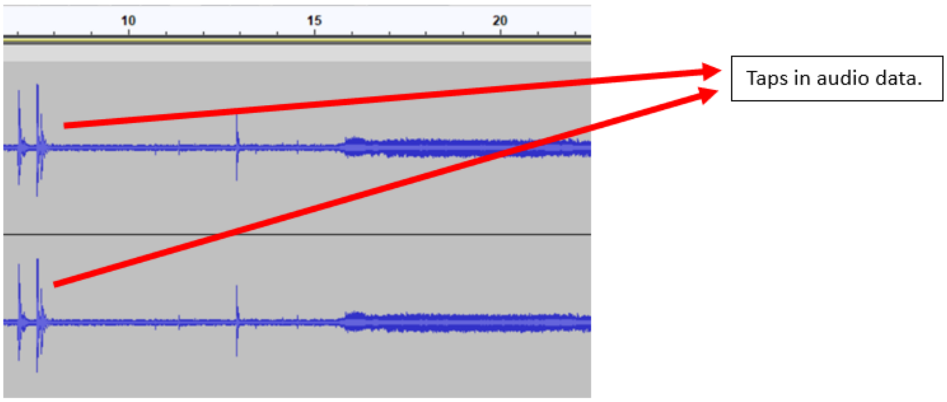

Figure 4: Taps visualized in the audio file.

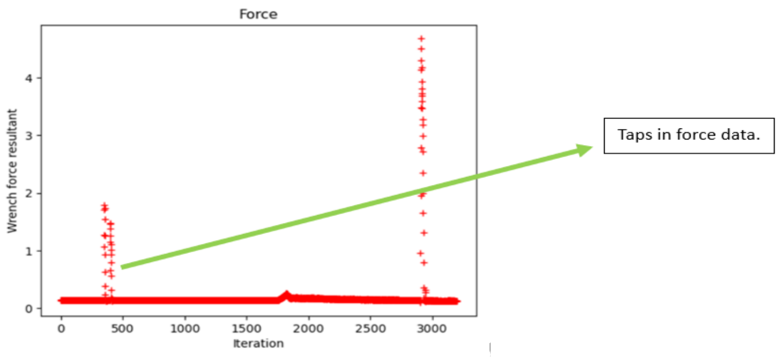

Figure 5: Taps visualized in force data (Wrench-force measure in N)

Signal Processing:

After synchronization, samples of 8.04 seconds of drilling sound were extracted from both the wav files and the rosbag files.

There was a total of thirty samples, ten from each phantom. To remove the background noise, these samples were passed through a high pass filter with the cut-off frequency set at 8,000Hz.

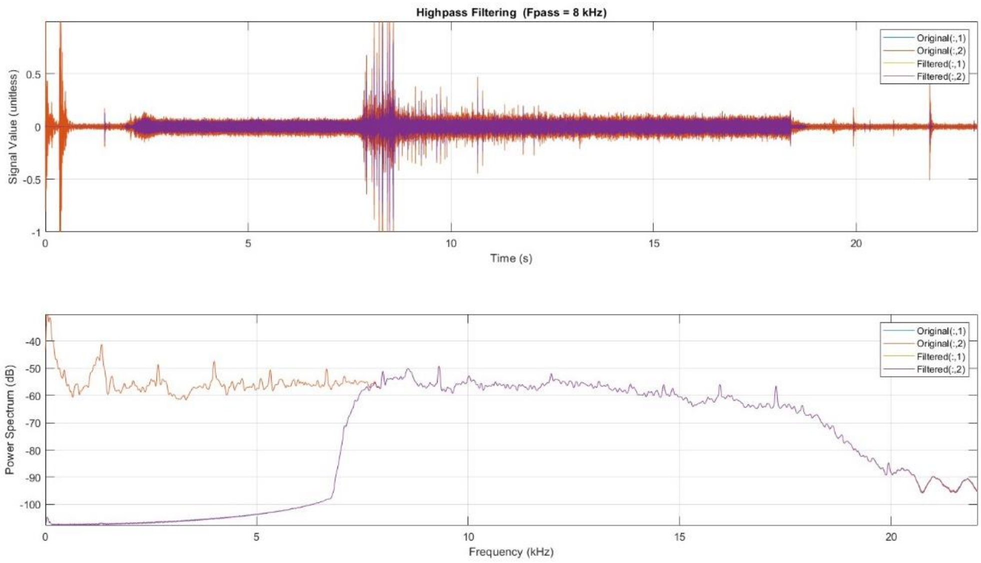

Figure 6: High pass filter with 8000 Hz as cut-off frequency.

To study the effect of density on the audio, single-sided amplitude spectrum plots were studied. The offset in the wrench-force samples was fixed by shifting the entire sample by the minimum value of that sample. The resultant of the wrench-force samples was calculated and plotted.

These results will be further discussed in the results section.

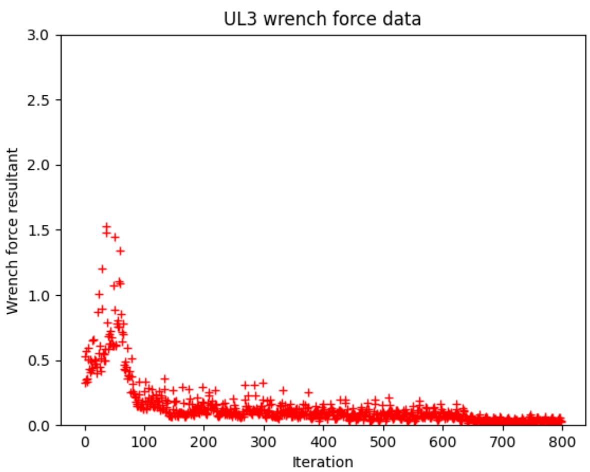

Figure 7: Force resultant for Upper Limit 3 (Wrench force resultant in N)

Results:

There was a total of eight samples for LL, seven samples for Avg, and seven samples for UL.

Audio Analysis:

It was observed that the amplitude of the frequencies increased as the density of the phantom was increased.

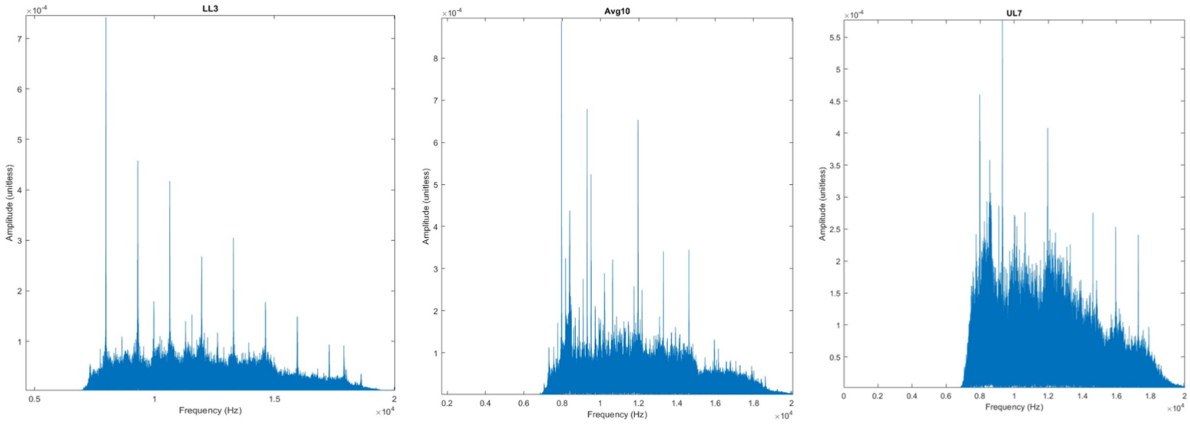

Figure 8: Single-sided amplitude graphs for LL3, AVG10, and UL7

The highest amplitudes for the LL, Avg, and UL phantoms were observed at 0.0007, 0.00099, and 0.00103 units respectively. There was a prominent increase in amplitude for the 8000 to 16000 Hz region.

Force Analysis:

For, the gamma sensor, was observed that all wrench-force plots had a sudden increase in the start followed by a steady decline which eventually reduced to zero. The sudden increase is associated with the drill drilling down into the phantom.

It was observed that the wrench-force value increased with the increase in the density of the phantom.

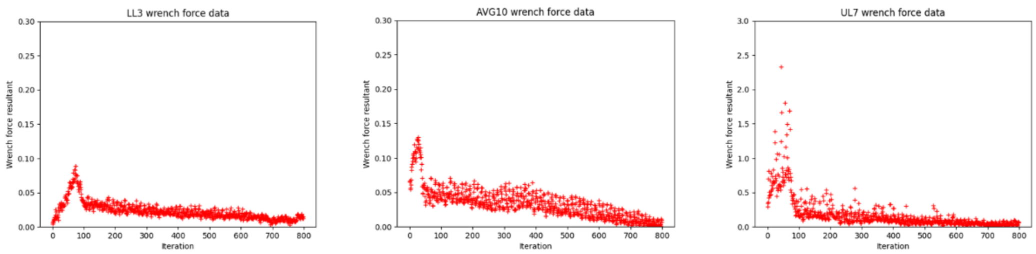

Figure 9: Force analysis for wrench-force data (Wrench-force measured in N)

With an increase in density, the max wrench-force value increases from 0.0146 N in LL to 0.033692 N for Avg and 0.1610 N in UL.

Progress Evaluation:

Dependencies:

Failure to not meet any of the given dependencies would have resulted in a complete stop of the project since data collection would not be possible.

Dependency	Need	Status	Follow-up	Contingency Plan	Deadline
Force-sensing Drill	Force data collection	Acquired	N/A	Obtain another force-sensing drill that can fir on the Galen Robot	21st Feb
Microphone	Sound data collection	Acquired	N/A	Obtain another microphone to record sound	21st Feb
Phantoms	To drill onto for data collection	Acquired	N/A	Request more phantoms to be printed	21st Feb
Access to MockOR	To work on the project	Acquired	N/A	Work on the project under supervision	23rd Feb
Computer with ROS, Linux and Python	Modelling and implementation of function	Acquired	N/A	Use Virtual Machine on laptop	28th Feb
Access to Galen Robot	To collect data	Acquired	N/A	N/A	1st March

Figure 10: Dependencies for the project

Adherence to Deliverables:

The minimum deliverable was completed during the duration of this project. The data set was uploaded to Teams where it can be accessed for future use. The expected deliverable was partially completed with basic modeling of the data done. It had been evident since the start that the maximum deliverable was not possible during the duration of this project and hence wasn't started.

Management Plan:

The management plan involved:

a. Weekly meetings with mentors.
b. On-demand meetings with Prof. Peter Kazanzides.
c. All data collected was uploaded onto a Microsoft Teams group that has already been created.
d. Communication Platforms: Microsoft Teams, Messages, and Emails

Conclusions:

Discussion:

With an increase in the density of the phantom, there was an increase in the wrench force detected by the gamma sensor during drilling. The maximum value observed for LL was 0.062N, Avg was 0.1439N and UL was 1.698096N.

With an increase in density, the amplitude of frequency for the audio file increased, with peaks reaching higher values and a prominent increase in the 8kHz to 16KHz region. The highest amplitudes for the LL, Avg, and UL phantoms were observed at 0.0007, 0.00099, and 0.00103 units respectively.

Next Steps:

The next steps for this project involve:

1. More in-depth modeling of the data acquired from data collection.
2. Collecting another data set with better synchronization.
3. Mathematical relation and implementation of the modeling into the simulator.

References:

1. Hoffmann, P.F., Gosselin, F., & Taha, F. (2009). Analysis of the drilling sound component from expert performance in a maxillo-facial surgery.
2. Badia, A., Cook, D., & Tunstall, H. (2021, July 19). Surgical drilling: Surgeon perspective on improving care standards. BONEZONE. https://bonezonepub.com/2021/07/19/surgical-drilling-surgeon-perspective-on-improving-care-standards/
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4. Density. Density " IT'IS Foundation. (n.d.). https://itis.swiss/virtual-population/tissue-properties/database/density
5. Munawar, A., Li, Z., Nagururu, N., Trakimas, D., Kazanzides, P., Taylor, R.H., & Creighton, F.X. (Sent for approval to IPCAI). Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond.
6. Chen, X., Sun, P., & Liao, D. (2018). A patient-specific haptic drilling simulator based on virtual reality for dental implant surgery. International Journal of Computer Assisted Radiology and Surgery, 13(11), 1861–1870. https://doi.org/10.1007/s11548-018-1845-0