Low-Latency Virtual Reality Visualization of OCT Volumes for Teleoperated Robotic Microsurgery

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BACKGROUND

Problems

- iOCT (Intrasurgical Optical Coherence Tomography) provides high-resolution volumetric images that reveal tissue microstructures critical for microsurgery.
- Exploiting this data in a surgical environment is difficult.
- Frame rates of **120 fps or higher** is an important threshold for avoiding motion sickness in Virtual Reality [1]
- **Using Virtual Reality, we can stream and render these 3D volumes with a digital twin for tool alignment, depth perception, and interactive volume manipulation**

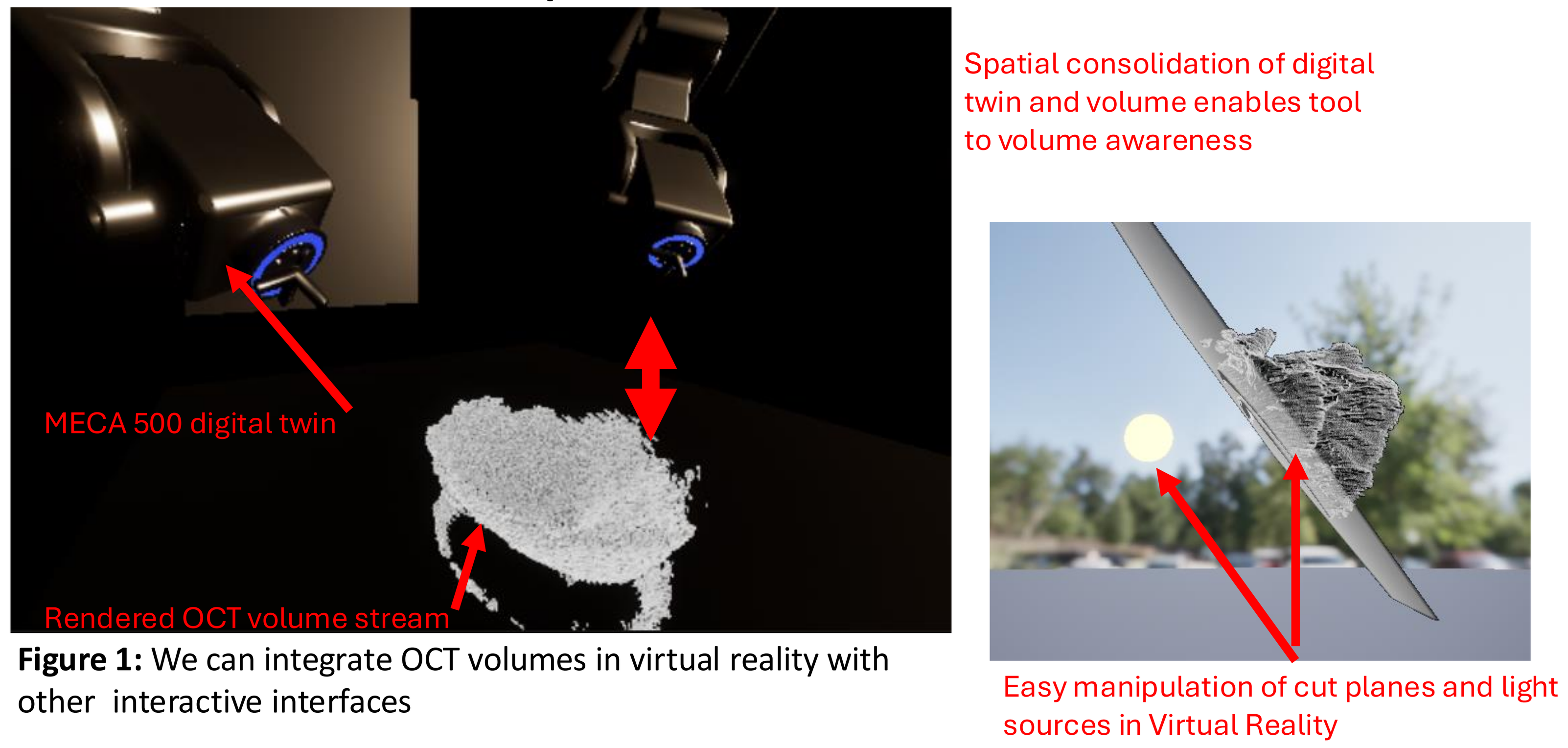


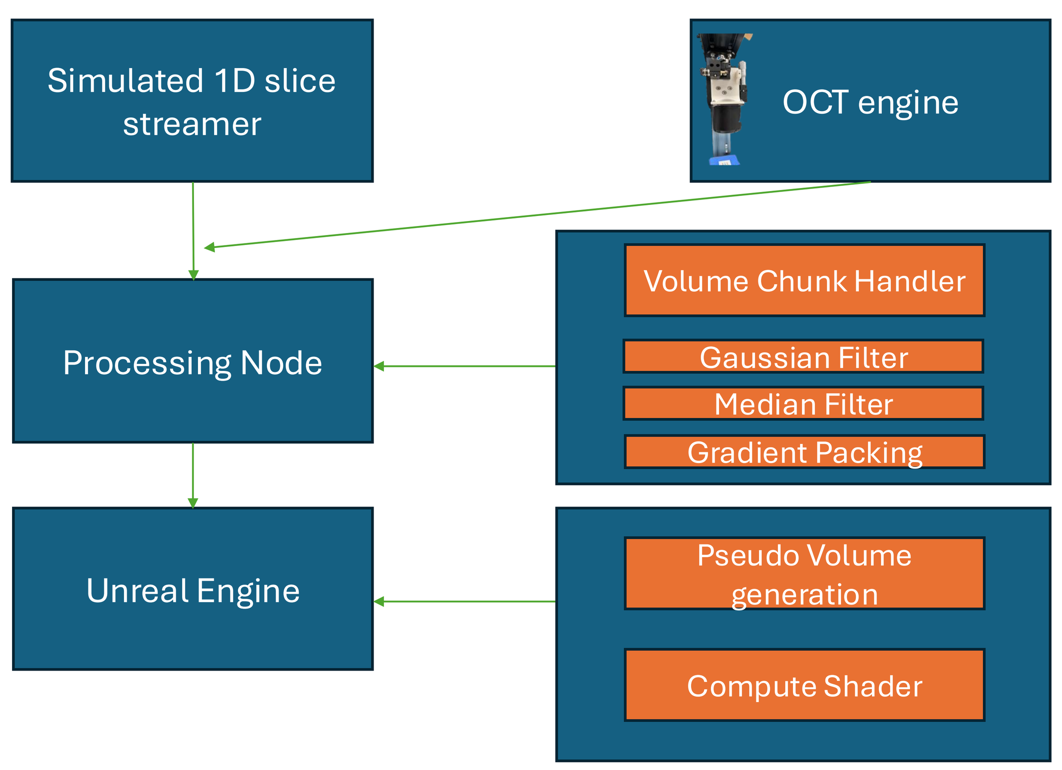
Figure 1: We can integrate OCT volumes in virtual reality with other interactive interfaces

Solution:

- **Pipelined volume processor node that processes raw OCT slices into edge-aware OCT slices for detailed rendering**
- **Precomputing of edge gradients in processing node and adaptive raymarching in rendering node for acquisition and display of OCT volumes**

OCT Processor and Renderer

Our pipeline involves three nodes that are all networked through **DDS (Data Distribution Service)** protocol. Our sender node is a networked OCT engine that sends raw data to a filtering node. In our study, we simulate 1D slices using a pre-acquired OCT file. The filtering node computes a gradient from the raw slices to send to our Unreal Engine rendering node. The render node visualizes the digital twin and OCT volumes, using the precomputed gradient to quickly compute a shaded volume in real time.



Sender acquires live volumes from our OCT laser.

Processing Node receives raw volumes over the network and outputs an optimized format for the rendering node

Unreal Engine is responsible for rendering data streams together and handling Virtual Reality interaction. This facilitates a future ergonomic surgical environment scheme

Figure 2: Our system distributes OCT acquisition, processing, and rendering across multiple nodes

Data Pipeline

Dispatch: Receive a new slice over DDS.

Blur: Apply a Gaussian blur to the dispatched slice and resize the slice size

Median: Apply median filter using slice adjacent slices in the Blur and Gradient stage. Threshold the image to reduce the background.

Gradient: Apply gradient packing using adjacent slices in the median stage

Retire: Send packed gradient slice in the retire stage over DDS to the Unreal Engine receiver

Resize: clear all stages

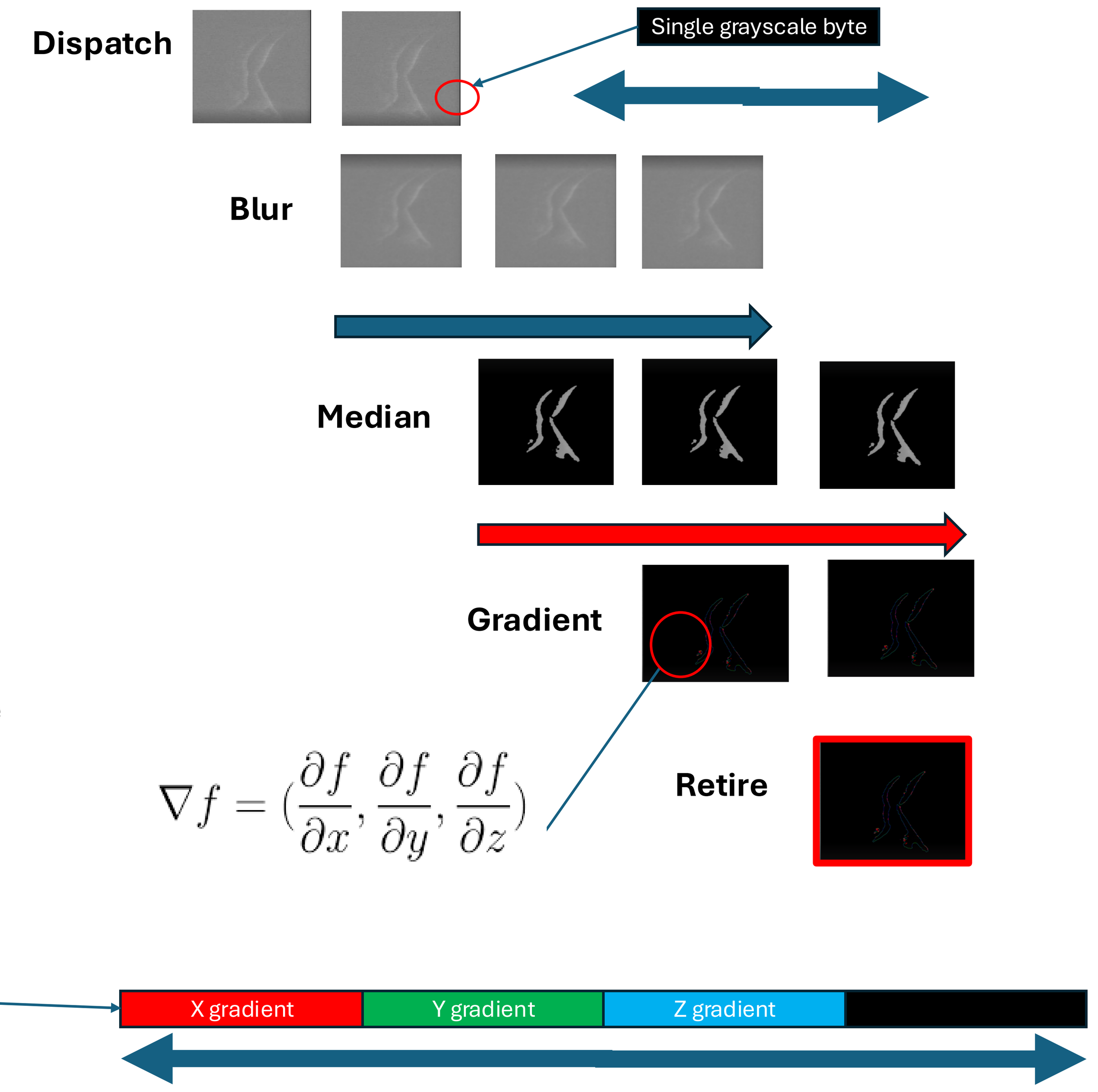


Figure 3: The OCT processing node converts raw data from a networked OCT acquisition engine into a gradient packed slice format for low latency rendering by the Unreal Engine node. We use gradient packing to pack the gradients into an array entry. Our packed slice format is four times larger than the raw data slices to decouple gradient operations from the compute shader. A single pixel packs edge information.

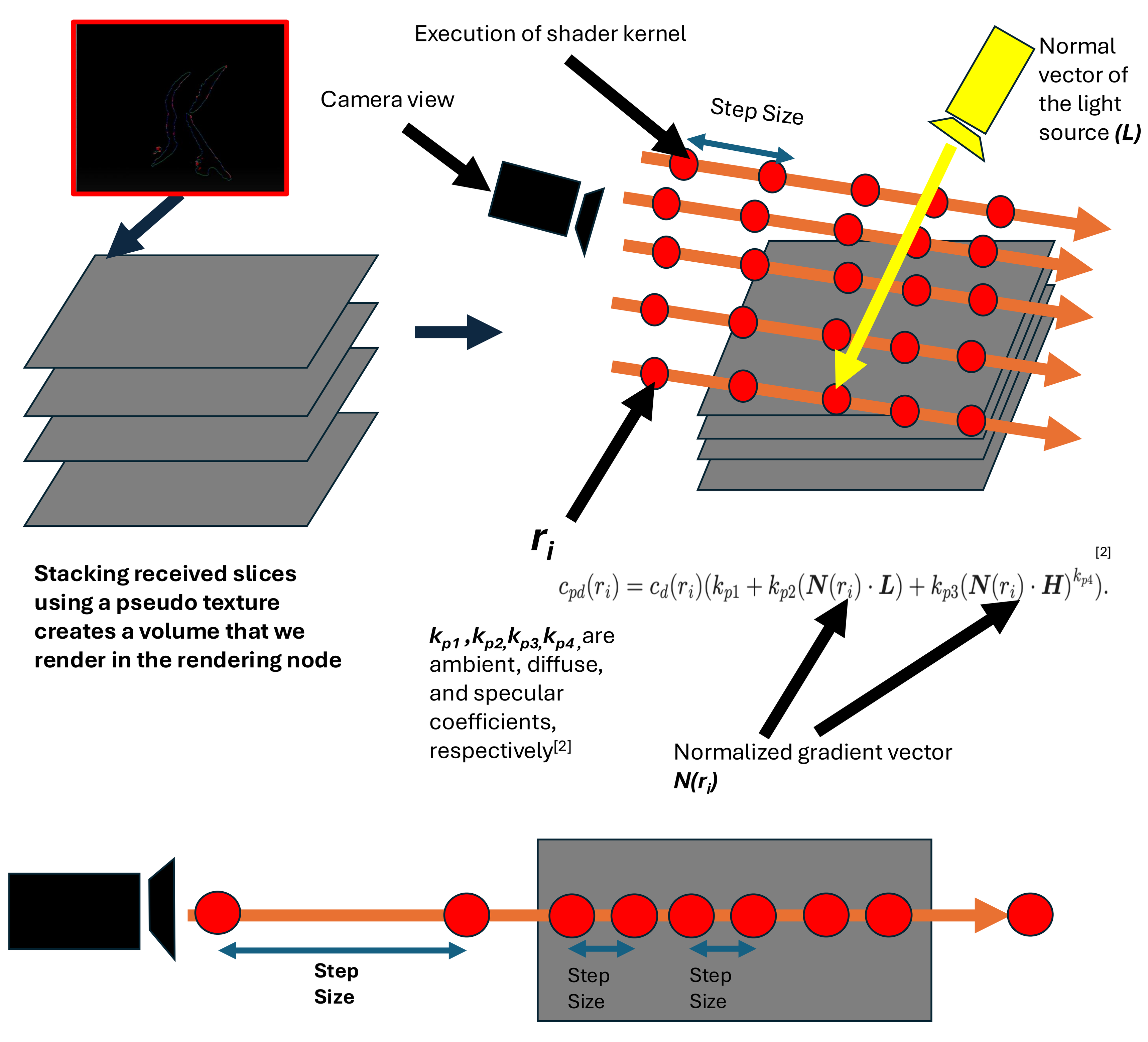


Figure 4: By integrating a custom compute shader with Unreal Engine's pseudo-volume textures, we render Phong shaded volumes in a virtual reality surgical environment. Integrating adaptive raymarching, we sample our volume with the rendering kernel more densely when we are in a volume, saving compute.

Results

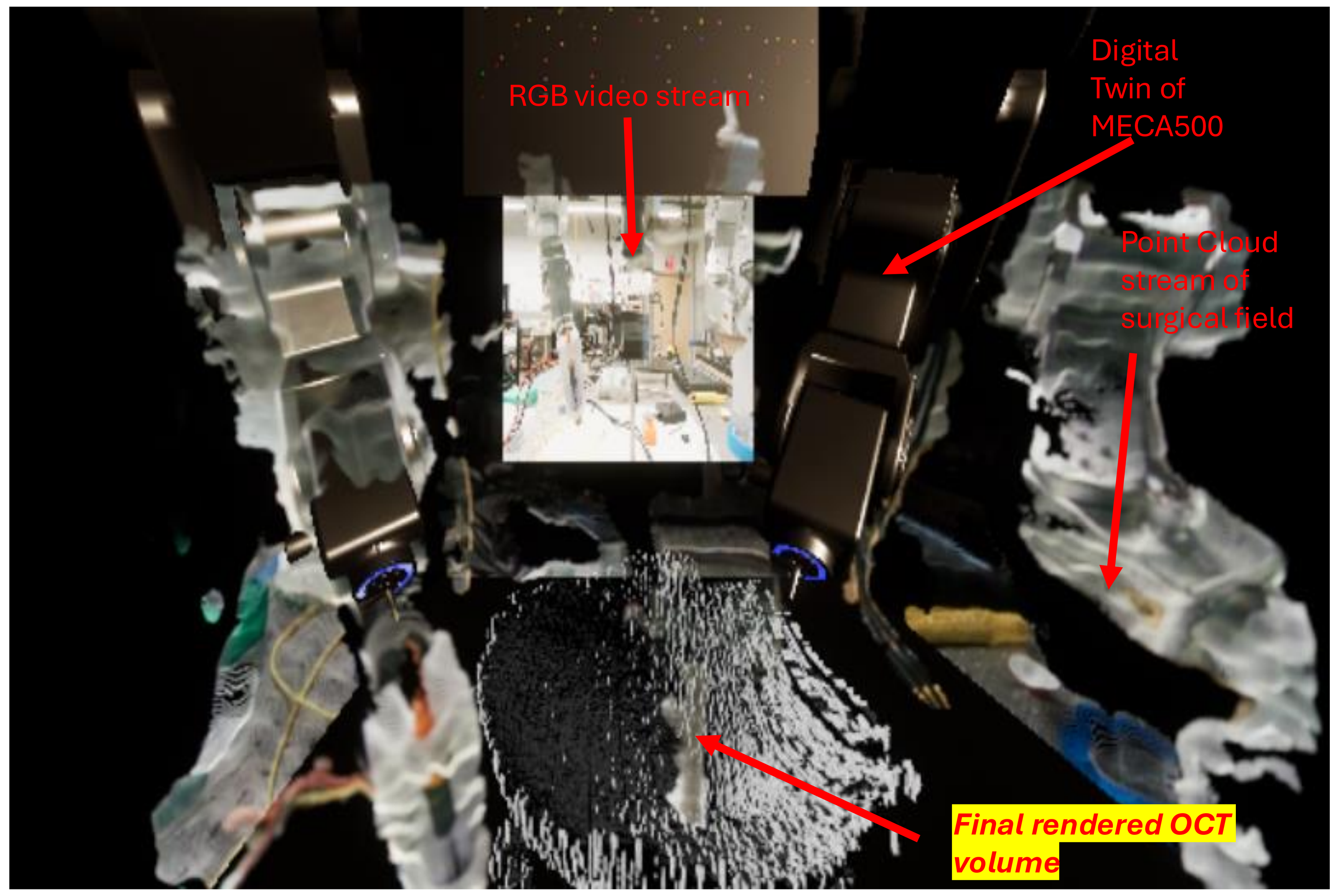


Figure 5: Final rendered OCT volume in Unreal Engine shows important ocular details in real time made possible through the application of a Phong shader. The Virtual Reality environment also integrates a digital twin. We can calibrate of the volume in relation to the digital twin and surgical environment.

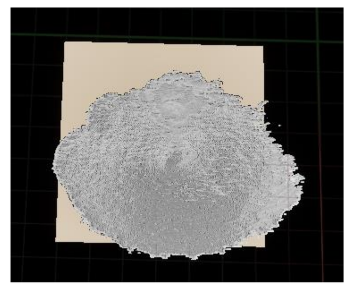


Figure 6: top view of rendered volume used to generate frame rendering times

Frame rendering time (adaptive step)	Frame rendering time (fixed step)
6.3 milliseconds	8.2 milliseconds

Table 1: We use the Unreal Engine profiling tool to acquire frame rates for the VR view of (500*500*1372) OCT volumes on our system. We position the VR view to capture from a top-down angle and average the measurements over a period of 3 seconds to get an average with and without adaptive raymarching. As seen in the table, the frame rendering time meets our 120Hz / 8.3ms frames per second threshold for display latency. We use chrono on the Unreal Engine node to measure average latency between slice dispatch and slice acquisition *(n = 24)* on the rendering node to be 14.6 milliseconds. Analysis was done on a private ethernet network

DISCUSSION

Using this framework for serializing and rendering OCT volumes, surgeons can manipulate streamed OCT volumes with tools such as cut planes and light vectors to expose important details. Interactive OCT volumes streaming to a VR environment facilitates teleoperated, robotic procedures.

Future work will improve this system by:

- Implementing and performance testing for sending multiple slices at a time
- Further GPU and network optimizations to achieve higher OCT update rates
- Integration of the OCT streamer with an ergonomic surgical environment and intuitive controls
- Analysis for lossy network conditions

REFERENCES

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