Virtual Reality to Enhance Surgical Robot Development and Control

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***Abstract*—This work investigates how virtual reality can be used with the Robot Operating System (ROS) to create and test virtual control schemes for surgical robots while leveraging existing development pipelines using the open source VRViz software. The work includes a case study of a vitreoretinal surgical robot and user study evaluating different sensor display methods and control schemes.**

***Index Terms*—medical, robotics, control, virtual reality**

I. Introduction

Virtual reality is being slowly applied for the exploration of 3D datasets and viewing of high-fidelity 3D models. However, less attention is being paid to a flexible system for displaying sensor data and providing real-time feedback and control of robotic systems. This article presents an application of VRViz, an open source virtual reality software package, to controlling and interfacing with a surgical robot.

II. Background

A Virtual Reality (VR) system tracks the pose of the user, and then streams a stereo video of a virtual environment rigidly aligned to a real world coordinate frame, commonly the floor, to his/her eyes. This creates an immersive environment wherein 3D models and sensor streams can be explored and manipulated in previously impossible ways. VR has been investigated for medical applications for many years [1], and has been available in a consumer-grade product since 2016 [2]. This has created a number of off-the-shelf VR hardware products and open software ecosystems such as Valve Software's OpenVR [3].

In order to allow more comprehensive robotic design ecosystem, the Robotic Operating System (ROS) was introduced in 2009 [4]. It enables design and development to be tested on simulation and prototypes while taking advantage of a wide range of community tools, libraries and robotic functions. ROS is widely used across academia and industry for development, and many robotics teams have already created ROS models and simulations for their robot systems.

In this paper we present the open source VRViz software package for development and control testing of surgical robots, expanding upon earlier work with VRViz [5], by presenting additional functionality developed for the VRViz project as well as a user study comparing body-centered and ground-centered robotic control displaying different sensor streams allowing evaluation of the utility of the VRViz software package.

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Open source code with an MIT license at https://github.com/RViMLab/vrviz

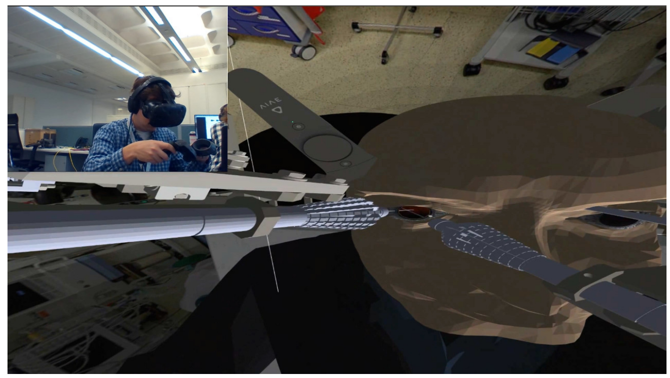

Fig. 1. Example usage of VRViz from [5]. Inset shows user operating controls, main image shows the view being sent to the left eye of the headset.

III. Methods

VRViz was developed in C++ with OpenGL using the OpenVR library to communicate with SteamVR. Further details of dependencies and full source code can be found on GitHub [6].

In order to facilitate ease of use for robot developers, VRViz seamlessly integrates into the ROS system. It subscribes to standard ROS messages for sensor data and publishes the state information of the user over standard ROS protocols, allowing its simple integration into an existing robotic research pipeline. Additional sensor types were implemented for this work, and have been merged into the VRViz project.

1) Sensor Visualization: The primary sensor type which is currently used in surgical robots is a stereoscopic image pair. This is well suited to the virtual reality environment, as the headset provides different images to each eye to create the stereoscopic effect. If the cameras are part of a larger robot, the images can either be displayed in the location of the camera to provide context for how the images were captured. The images can also be displayed directly in front of the user, similarly to how a standard stereoscopic headset would function.

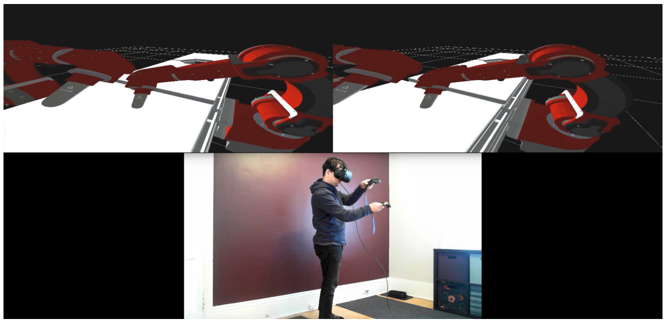

Fig. 2. Example of controlling a surgical robot, CORVUS [7], using hand position. The lower image shows the author directing the robot, and the upper two images show the views being sent to each eye.

The 3D models from the robot design can be visualized. If there are joint sensors in the robot, the forward kinematics can be solved and the articulated model can reflect the state and the shape of the robot. This can provide important context to the user, such as self-collision of the robot or how maneuvering would impact the surrounding area.

Another sensor message is 3D point clouds. As robots are provided with more advanced sensors, such as time of flight distance sensors, or advanced stereo reconstruction, it becomes possible to create a 3D map of the environment around the robot. This map can be used to provide context for user, especially when combined with the 3D model of the robot.

Additionally a wide variety of visualization markers are supported. These provide simple shapes, such as cubes or cylinders to represent fiducials or more complicated meshes from preoperative scans, such as skeletal structures to provide further information to the user. These sensor streams and visualization tools can be used together to display both raw data and additional perception or models together in 3D.

2) Robot Actuation: Since the user's head and hands are being tracked with 6 degrees of freedom, a wide variety of robot control schemes opens up. For robots limited to 2D motion, navigation can be commanded by casting a targeting ray from the user's hand. This would be paired with the ability of the user to navigate around the scene in order to follow the robot or move to a new area of interest.

For 3D motion, the user can fully manipulate the scene in all six degrees of rigid motion, as well as scale the scene larger or smaller. This allows the user to observe the scene from a novel vantage point. The robot can then be commanded to move to the position of the user's hand. An example of this control scheme can be seen in Figure 2.

The scene can be static, staying fixed to the world frame, or move along with the robot. This can enable exploration of different control schemes, such as the robot attempting to travel in the direction that the user is looking. This kind of point of view control also enforces that the user is seeing the latest sensor data, as opposed to a free motion allowing the user to try to explore unreachable areas.

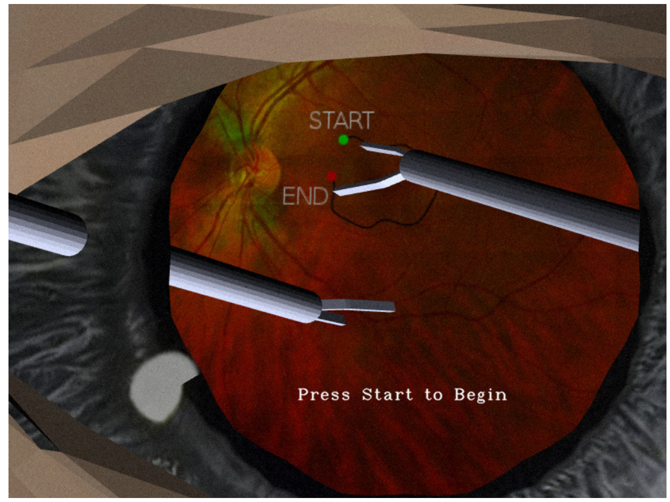

Fig. 3. Simulated binocular microscope control scheme. Left eye image shown here. Note that as this is a simulated microscope view, the camera location and field of view were fixed at this location for the entire test.

A. *Experimental Design*

In order to evaluate the usefulness of the system, a user study was designed to compare two different virtual reality control schemes using different sensor setups for the same surgical robot, a design of a vitreoretinal surgical robot currently under development [8]. This vitreoretinal surgical robot lends itself to virtual reality because retinal surgery includes high definition optical stereo microscopes and additional preoperatively and intra-operatively acquired sensor data such as Optical Coherence Tomography (OCT). Both tests were performed in simulation to allow testing of novel sensor combinations.

The first control scheme was designed to simulate a standard binocular vitreoretinal microscope setup. These microscopes are widely used in vitreoretinal surgery, and provide high definition stereoscopic images to the surgeon. The virtual microscope was kept at a fixed location, and the microscope remains in roughly the same location relative to the patient's eye during surgery. The user then performed a mock cutting task by looking through the microscope where the surgical tool tips were controlled by the VR controller location relative to the user's head. The time and accuracy of the task were reported back to the user in real-time through a heads up display, as shown in Figure 3.

The second control scheme tested was a more immersive virtual reality environment, with a 3D model of the retina and surrounding structures which can be freely explored in 3D, allowing the user to choose the vantage point from which to see the scene. This type of control would require more advanced sensors than are currently used in surgery such as a 3D scanner combined with a Simultaneous Localization and Mapping (SLAM) system to create a detailed 3D model of the eye intraoperatively. This could also be fused with preoperative information, such as a fundus image or vascular map. In order to simulate a mock 3D environment, a fundus image of an eye

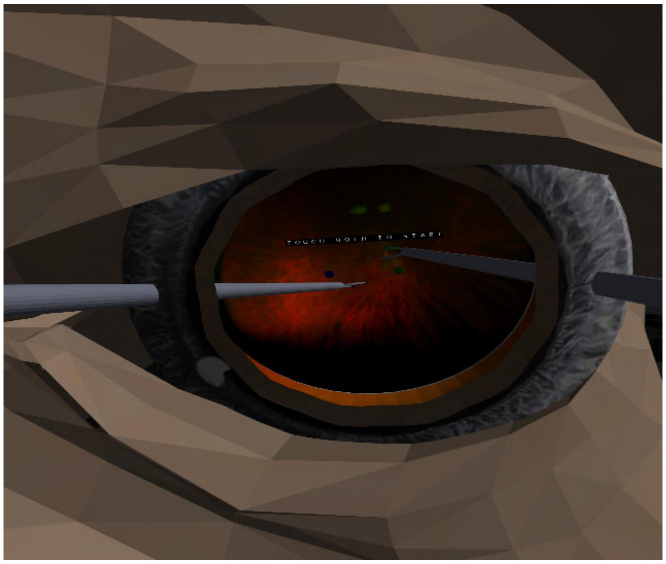

Fig. 4. Simulated SLAM control scheme. Left eye images shown here. Note that this test allowed free movement of the user, so the camera position was not fixed during the test and the user could explore the scene and observe from different vantage points.

TABLE I
RESULTS OF USER STUDY.

	UI	Controls	Immersion	3D Benefit
Microscope	4.00	3.25	3.25	3.5
Simulated SLAM	4.25	4.25	3.75	4.25

was projected onto a 3D model of an eye, and the parts of the eye and patient not covered by the fundus image used generic 3D models. The user performed a mock bimanual task, and the time and accuracy of the task were reported back to the user in real-time through a heads up display, as shown in Figure 4.

The users were then given a post-test survey where they were asked to evaluate the usefulness of each control scheme and sensor suite. They were specifically asked to rank each test from one to five for user interface (UI), control scheme, immersion and benefit of 3D.

IV. RESULTS

The simulated microscope test ranked lower in all four metrics than the simulated SLAM test. The average score for the microscope test was 3.5 and the average for the SLAM test was 4.1. The average results for all four categories are shown in Table I.

V. CONCLUSION

The test results show that both scenarios were received positively, and that nonstandard Human/Computer interface and control schemes could be feasibly developed in virtual reality with good reception from users. Further study is needed to see if these results generalize to more realistic surgical simulations can still benefit from virtual reality, and whether novel control algorithms can make use of the tight ROS integration of the VRViz software.

Future work will investigate further the uses for VR in surgery but this work can have a wide range of applicability to the control of other types of robotic systems. Through Danfoss (Nordborg Denmark) J.J.O. will be investigating the use of VRViz for design, remote operation and supervision of robotic off-highway vehicles.

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