An Interactive Demonstration of Collaborative VR for Laparoscopic Liver Surgery Training

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***Abstract*—We introduce a collaborative virtual reality (VR) system for planning and simulation in laparoscopic liver surgery training. Patient image data is used for surgical model visualization and simulation. We developed two modes for training in laparoscopic procedures: *exploration* and *surgery* mode. Surgical joysticks are used in surgery mode to provide training for psychomotor skills and cooperation between a camera assistant and an experienced surgeon. Continuous feedback from our clinical partner comprised an important part of the development. Our evaluation showed that surgeons were positive about the usability and usefulness of the developed system. For further details, please refer to our full article [1] and additional materials.**

***Index Terms*—Laparoscopic surgery, collaborative VR, surgical training, immersive virtual reality**

I. Introduction

Virtual reality (VR) has been used to visualize complex medical data effectively, and it is currently used for surgical training to improve psychomotor skills. Various laparoscopic simulators have been proven as a surgical training for laparoscopic surgery [2]. However, they are limited due to a low level of realism of simulation, using abstract models, and the usage of conventional monitors with an out-of-context environment.

In previous work, we developed a combination of a laparoscopic simulator with a head-mounted display (HMD) that provides the immersion of the training environment [3], [4]. Nonetheless, its limited use is due to the integration of video output from the simulator and difficulties in remote collaboration.

Collaboration in an immersive virtual environment emerged as an essential research topic. It allows multiple users to join in the same virtual environment and work together simultaneously, whether they are remote or co-located. However, there are still not many collaborative HMD applications for medical specialties [5], particularly for laparoscopic liver surgery.

In this demo, we introduce a collaborative VR system *CollaVRLap* for laparoscopic liver surgery planning and simulation. We developed two modes for laparoscopic liver surgery procedures: *exploration* and *surgery* mode. A patient data is used for model visualization and manipulation because it is useful for training of laparoscopic procedures. Moreover, surgical joysticks (Simballs) are used to enable users to cooperate, communicate, and improve their psychomotor skills. Continuous clinical feedback from laparoscopic surgeons led us to optimize the visualization, interaction, and synchronization of the system.

II. System Design and Implementation

A. CollaVRLap system

CollaVRLap enables collaborative users to connect in the same virtual training environment and manipulate the same patient data. We assembled different technologies such as Unity, Nvidia FleX, and Cubiquity to create useful features for cutting, clipping, and bleeding simulation.

We used a computed tomography (CT) scan, which is used in the liver surgical routine. In this step, the data was smoothed and the image resolution was reduced to $242 \times 223 \times 350$ to enable a real-time cutting functionality. The image data is stored in a voxel database to generate a surface by preserving the volume density, which represents the internal model structure in an occupancy grid data. During the cutting simulation, if there is a modification on the model occupancy grid, the system will regenerate the volumetric mesh with a surface painting of layered texture and apply a mesh smoothing around the cutting area.

The bleeding simulation is realized by using the fluid simulation of Nvidia FleX. In CollaVRLap, vascular structures and tumors are visualized inside the liver model. We simulated the cutting with a possibility to clip the vascular structure. Users should be cautious of vessels during liver cutting; if they accidentally cut onto the vessel, a vascular bleeding is simulated. After the clip is placed on the affected vessel, the bleeding stops. The system also provides a possibility to render the liver in a semi-transparent manner. This semi-transparent liver reveals the inner vascular structures and allows for more natural planning.

B. *Exploration mode for surgery planning*

The collaborative users are connected and joined in the VR room and virtually perform surgical planning. Through an enlarged 3D organ model, it provides a basis for exploration and planning in laparoscopic procedures. As shown in Fig. 1, two collaborative surgeons can explore and create surgical planning on the patient data before going through to laparoscopic intervention.

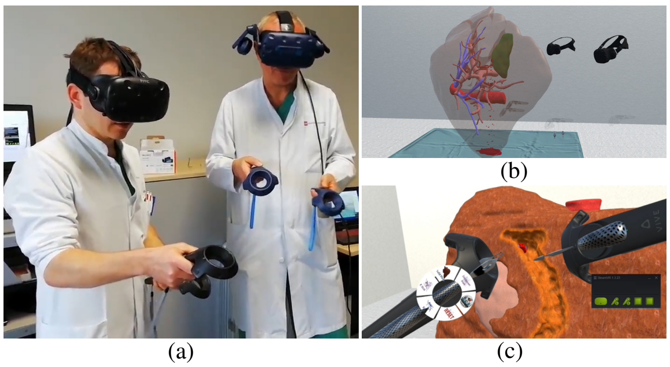

Fig. 1: Two surgeons are using exploration mode to explore and plan on the patient data. (a) Surgeons perform in the real world with the use of HTC Vive controllers. (b) Semi-transparent liver reveals vascular structures and tumors. (c) Cutting is simulated with the possibility to clip on the vessel.

C. *Surgery mode in the virtual operating room*

In laparoscopic liver surgery setting, an experienced surgeon controls the surgical instruments, and a *camera assistant* holds the camera (see Fig. 2). The Simball joysticks are used in this surgery mode. Moreover, the 3D organ model is placed inside a phantom, and it is captured by the virtual laparoscopic camera. The captured view is projected to a virtual monitor with the setting of the operating room. The experienced surgeon controls Simball's grasper, cutting tool, and foot pedal while the camera assistant controls only the Simball camera. Both users would be able to see the captured view and simulate simultaneously from the synchronization of the virtual instruments over the network. This procedure enables the surgeon and camera assistant to cooperate, communicate, and improve psychomotor skills.

III. Evaluation and Results

We evaluated our first prototype with three laparoscopic surgeons with previous experience of a laparoscopic simulator. The aim included determining the usability and usefulness of the proposed system as well as gathering feedback for further improvement. Using real patient data was considered an advantage compared to the previous simulator. For both two modes, the system provides abilities to explore, interact, and perform the laparoscopic simulation with collaborative users as team training. The surgeons were positive and evaluated the system as a good basis for training and further clinical evaluation.

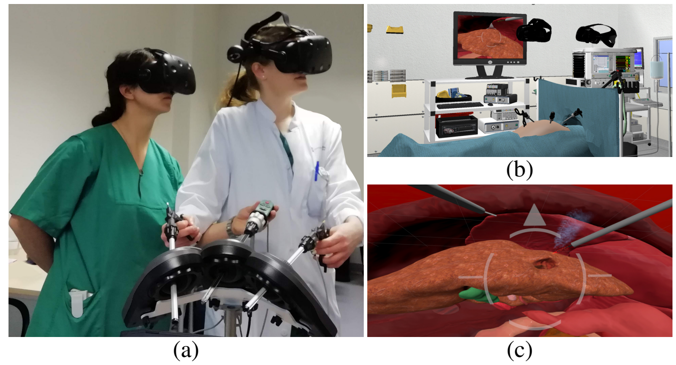

Fig. 2: Two surgeons are performing the surgery mode of laparoscopic setting. (a) Surgeons perform in the real world. (b) Surgeons virtually cooperate in the virtual operating room and perform the cutting simulation (c).

We tested our system with two computers in a local network. The cause of a low frame rate happens during the cutting simulation. The size of image resolution also results in the considerable computation of the voxel grid for real-time cutting. The average network latency for the exploration mode is 32.06 ms, and the surgery mode is 34.92 ms.

IV. Conclusion and Future Work

We introduced a collaborative VR system for laparoscopic liver surgery procedures. This VR system enables clinical trainees to improve the immersion and collaboration of training. The developed prototype offers potential for future development and collaborative remote training. This work also builds a basis for a comprehensive clinical evaluation and opens new directions for surgical training. Future work aims to improve system performance, visualization, and supplement additional scenarios.

Acknowledgment

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