MRMSim: A Framework for Mixed Reality based Microsurgery Simulation

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Abstract

With the rapid development of the computer technologies, virtual surgery has gained extensive attention over the past decades. In this research, we take advantage of mixed reality (MR) that creates an interactive environment where physical and digital objects coexist, and present a framework (MRMSim) for MR based microsurgery simulation. It enables users to practice microanastomosis skills with real microsurgical instruments rather than additional haptic feedback devices. Both hardware design and software development are included in this work. A prototype system is proposed to demonstrate the feasibility and applicability of our framework.

Index Terms: Human-centered computing—Mixed / augmented reality; Computing methodologies—Modeling and simulation; Software and its engineering—Virtual worlds training simulations

1 Introduction

Microsurgical techniques are primarily used to anastomose micro blood vessels and nerves, which are widely utilized in modern surgical operations such as plastic surgery, transplant surgery, ophthalmic surgery, and artery reconstruction [7]. However, a qualified microsurgeon requires a very long learning curve to gain adequate anastomosis skills [7]. According to the types of the materials used in the training process, the traditional training models can be classified into two main categories: the *synthetic* model and the *biological* model [1, 2], as illustrated in Figure 1. However, the synthetic models, also known as non-living models that lack realism from the visual sense, and the biological models always face the issues related to the ethical treatment of animals and incur high costs in a long-term usage [1, 2]. With advances in computing technologies, especially in computer-aided simulation, surgical training is undergoing a rapid evolution. Virtual surgery simulation provides a visually plausible, non-hazardous and effective supplement to the traditional microsurgical training.

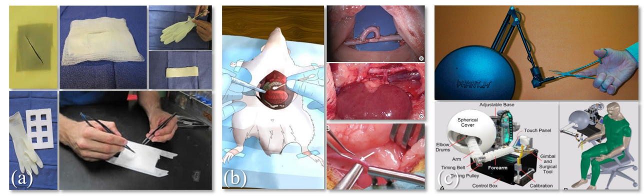

Figure 1: (a) Practice Card and Gauze & Tape models. (b) Live animal models include rat and rabbit [6]. (c) Haptic feedback devices for virtual microsurgery simulators [3].

Compared with the virtual reality (VR) based systems that put users in a fully digital world, mixed reality (MR) technologies create an interactive environment where physical and digital objects coexist. This feature expands the space of possibilities in microsurgery simulation. In this work, we propose a framework for MR based microsurgery simulation that leverages the affordances of MR. It allows users to practice on physical objects (artificial blood vessels) and use real microsurgical instruments rather than additional devices. The motion and deformation data are captured for the simulation procedure via a vision-based system. The realistic rendering intra-operative view of microsurgery is presented onto the lens of an HMD which can be considered as an effective substitute for the surgical microscope. This framework takes the advantages of traditional *synthetic* training models, which are low-cost, reusable and able to provide real tactile feedback without the need to sacrifice animals in the process. On the other hand, it generates an artificially controllable and visually plausible rendering result. This visual-tactile simulation increases the immersive experience compared with the traditional approaches.

2 Framework Overview

2.1 Hardware Design and Deployment

The framework can be divided into two parts, hardware and software. To provide users with experience that is similar to that of a real clinical operation, a workbench is designed, which is a container that wraps the devices and instruments in a compact workspace as shown in Figure 2. A magnetic arm system is employed to hold the essential components which can be easily adjusted to meet the different requirements.

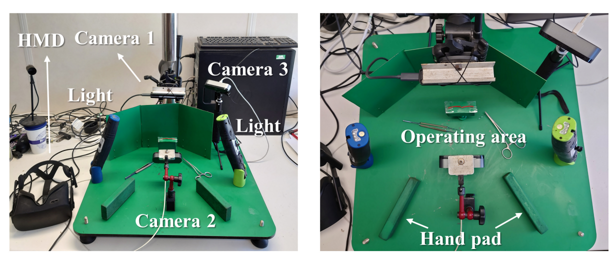

Figure 2: Workbench design. The essential components including an HMD (Oculus Rift), cameras (two monocular cameras and one binocular camera), lights, operating area and hand pads.

2.2 Software Design and Development

We divide the software system into several functional modules, including *vision-based tracking, anatomical modeling, realistic rendering*, and *display* modules. The tracking module deals with the tracking of physical objects include microsurgical instruments and artificial blood vessels. The motion and deformation data are collected and utilized to drive the simulation process. Modeling module generates organ models efficiently, and rendering module produces

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realistic rendering frames which are then presented to the final display module and observed by users.

Vision-based tracking module. The tracking of a single rigid object refers to estimating the six-degrees-of-freedom (6DoF) pose of the target object. However, the microsurgical instruments with local mechanical motions, such as the shearing motion of scissors and the clamping motion of forceps cannot be modeled as the simple 6DoF pose. Inspired by the TsFPS [9], we treat the compound motion as a combination of several local motions. As shown in Figure 3(a), several fiducial platonic solids (FPSs) are attached onto the instruments. The trajectories can be recovered by continuously estimating the pose of each FPS. As for the tracking of deformable tubes, we propose a semi-dense method instead of the dense feature tracking which is computationally intensive and slow. For every single frame in the loop, a fast shape matching method is utilized to extract the edge points of the soft tissues from multi-view images. These points are then mapped to the 3D models for deformation simulation via the position based dynamics method (PBD) [4].

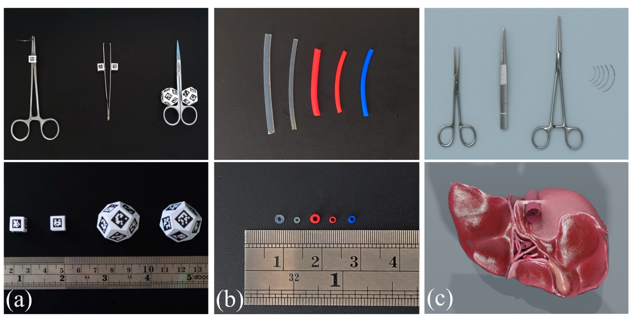

Figure 3: (a) Microsurgical instruments with fiducial platonic solids. The marker lengths of the hexahedron and dodecahedron solids are 5.1*mm* and 7.5*mm*, respectively. (b) Silicone tubes with different sizes. Tubes with 0.7 mm wall thickness and 2.0 mm diameter are employed as the artificial blood vessels in the experiment. (c) 3D models of microsurgical instruments and liver with blood vessels.

Anatomical modeling and rendering. We use an end-to-end learning-based framework for anatomical modeling. This module is inspired by (1) patient-specific modeling approach that reconstructs anatomical models from the patient-specific data [5] and (2) recent deep learning work in recovering 3D shapes from single 2D images. The design follows a two-step strategy [8], a CGANs architecture is used to train a generator that converts X-ray images to normal images. These normal images provide the silhouette and geometric constraints to the CNNs for the mesh predictor training. An X-ray shader is developed upon the relative depth of the mesh to generate synthetic X-ray images for network training. It is in line with the imaging principle of the X-ray scan. In addition, a Physics based rendering (PBR) pipeline with specialized materials is introduced to provide efficient and realistic rendering to the generated models. The rendering result of a generated liver model is shown in Figure 3(c).

3 Experiment

The experiment is conducted under a Windows 10 PC equipped with a 8 Cores 3.6 GHz CPU (Intel Core i9-9900KF), 32 GB of RAM, a GPU (Nvidia RTX 2080Ti) with 11GB of GDDR6 memory capacity, and an Oculus Rift HMD. Two Logitech webcams (1280 × 720, 60fps) and a ZED mini stereo camera (2560 × 720, 60fps) are employed to construct the camera system. A prototype system is developed, some results are presented in Figure 4.

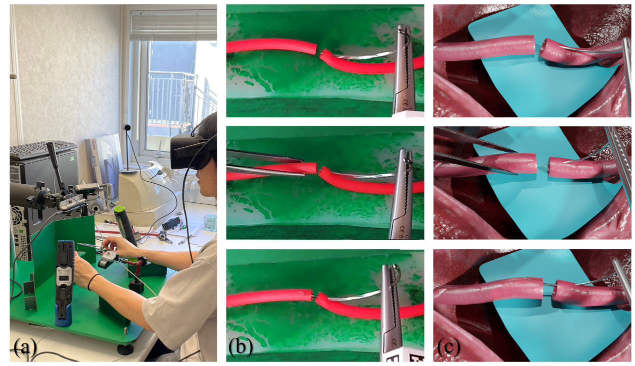

Figure 4: (a) User is allowed to use real microsurgical instruments instead of haptic devices. (b) Input frames that are captured by the top view camera. (c) Output frames that are presented to the user via the HMD.

4 Discussion

In this work, we presented a framework for the MR based microsurgery simulation (MRMSim). Although, current results have shown the feasibility and potentiality of our framework, there are still challenges need to be studied and solved. Simultaneously tracking multiple surgical tools and soft tubes dramatically increases the computational burden and affects the final performance of our current prototype system. A GPU-based implementation is imperative for our future work. Moreover, a comprehensive evaluation scheme will be introduced, both quantitative and qualitative analyses should be taken into consideration in the further system development.

Acknowledgments

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