THUMP: An Immersive Haptic Console for Surgical Simulation and Training

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Abstract. Telerobotic systems are revolutionizing minimally invasive surgery (MIS), giving the surgeon complete control over precise dexterous movements of tiny robotic instruments. Such 'surgery-by-wire' approaches also create unique opportunities for simulation and training, as the surgeon operates at a computer-mediated haptic console. Possible extensions include offline training in simulated environments and advanced guidance and mentoring during actual operations. To explore these options and further improve telerobotic interfaces, we have constructed a two-handed, fully articulating haptic console that provides force and torque feedback as well as a stereoscopic display.

1 Introduction

Surgical simulation has recently emerged as a strategy for improving training efficiency and reducing the reliance on patient procedures. Fueled by the popularity of minimally invasive surgery (MIS), simulators are viewed as a safe opportunity to practice surgical skills. In particular, virtual environments promise highly flexible, well controlled learning situations that can vary from simple tasks to rare and challenging problems [1, 5, 6].

The introduction of telerobotic surgery systems is alleviating some of the classic hand-eye coordination challenges and other limitations of traditional MIS [2, 3, 4]. It is also increasing the potential for training, as the surgeon conducts the procedure at a haptic console. Beyond simulation, this technology also enables advanced mentoring methods, ranging from telestration to co-piloting during surgery. The Two-Handed Universal Master Project (THUMP) allowed us to develop and construct a surgical training console to explore these possibilities.

2 Training Opportunities

Opportunities for surgical training can be divided into two categories: simulation and advanced mentoring. Interactive virtual environments simulate the surgical procedure (or specific aspects thereof) and have been the primary focus of previous work. A key quality of such environments is their ability to provide the operator with an authentic experience. Because its user interface is identical to existing surgical systems, the THUMP console can accurately simulate telerobotic surgery.

The second training category enabled by telerobotics is advanced mentoring. A teaching surgeon can take various levels of control or intervention in a regular procedure. Simple telestration allows the instructor to share the student's view and point or draw in three dimensions to indicate actions and locations. In co-piloting, the instructor's and student's hand movements track one another, so that the instructor may guide the student. Other options include play back of previous surgeries, in which a student follows recorded hand movements and haptic cues. Computer-mediation allows this spectrum of shared control between the teacher and student, which may even by adjusted during a procedure.

3 System Architecture

The THUMP haptic console incorporates stereoscopic goggles and two eight-axis da Vinci™ master mechanisms provided by Intuitive Surgical®[2]. The supporting infrastructure has been assembled from commercially available components, and custom software has been developed for hardware control and graphical display.

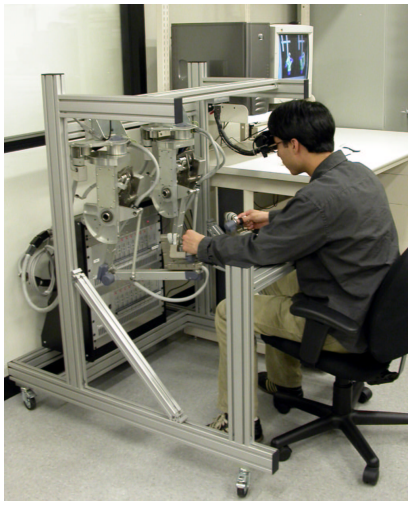

Figure 1: The THUMP console.

Sitting at the THUMP console, the operator views real or virtual images of the surgical site in the stereoscopic goggles, providing an immersive, three-dimensional environment. He holds the end-effectors of the two master mechanisms between thumb and index finger, as shown in Fig. 1, allowing the system to measure the position, orientation, and grip level of his two hands. A desktop computer running RTAI Linux computes the hardware control commands to apply appropriate reaction forces and torques.

In a virtual environment, the system simulates and can render both the master manipulators and the surgical tools to the operator. Simulating the master mechanisms allows prediction of collisions and may guide operators away from improper configurations. By construction, the virtual images track the real arms, as illustrated in Fig. 2. Each simulated tool follows the user's hand motion and generates resistance forces to prevent unattainable positions and velocities. Collisions between the rigid tools and soft tissue models will be added to provide a realistic environment.

4 Conclusion

Simulation promises substantial improvements in surgical training, and many simulators have been built for individual procedures or scenarios. The THUMP console provides an important new test-bed for telerobotic surgical training. Its two-handed haptic capabilities can provide force and torque feedback cues identical to those experienced during actual procedures. In addition, the THUMP console opens up opportunities for advanced mentoring, where a teaching surgeon can share control with a student. We hope such approaches will benefit surgical training and facilitate the adoption of telerobotic surgery.

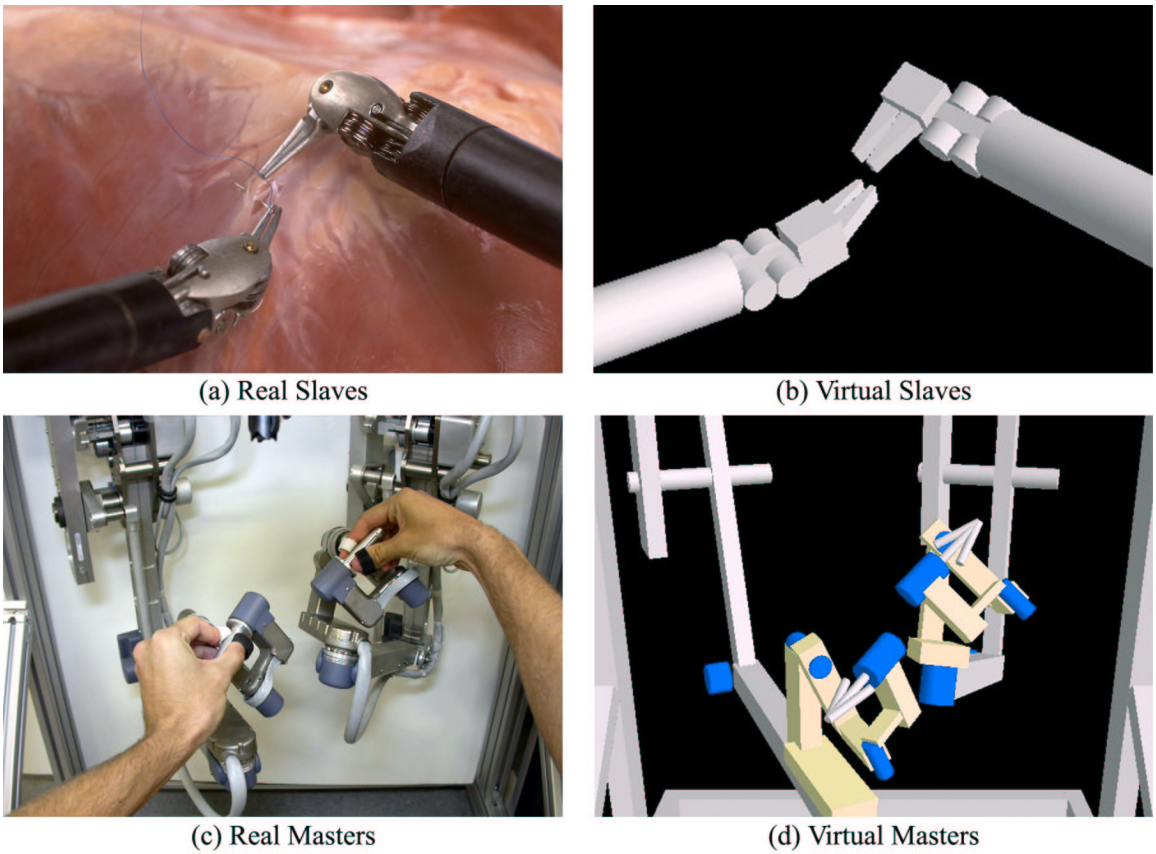

Figure 2: Real and virtual masters and slaves, as seen in equivalent configurations.

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