Endoscopic Surgery: The (better) VR Way

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Abstract

Virtual reality based surgical simulator systems are a very elegant approach to enhancing traditional training in endoscopic surgery. Even though a number of VR simulator systems have been proposed and realized in the past few years, studies have shown that most of these systems are far from providing a reasonably realistic surgical environment. This paper proposes approaches to surpass the limits by improving the most important components of VR-based endoscopic simulators. The feasibility of the proposed techniques is also demonstrated.

Introduction

Traditionally training in surgery is performed on living animals, cadavers and sometimes on real patients under expert supervision. Such an approach is fraught with risks and drawbacks like **casualty** and **morbidity** of the patients, null reproducibility of the actions, fundamental differences between humans and animals and **null reaction** of dead human bodies. Increasing pressure on maintaining consistency in quality of surgery and reducing possible risks due to the 'learning curve' have made this method unacceptable in early stages of surgical training. Also availability of an expert supervisor is not always possible.

Thus simulators are required to train surgeons and reduce the pressure on them by allowing them to make mistakes. Even though VR for medical professions is still in its early stages its advocators believe the future of medical education is **not "blood and guts", but "bits and bytes"**.

Concept of Operations

Surgery is mostly visual and manual. VR for surgery involves applications **of interactive immersive computer technologies** to help perform, plan and simulate surgical procedures. While surgical simulators require rich and accurate portrayal of visual information, they also need to **provide the sense of touch** to the surgeon.

Five separate units have been identified that work together in the simulator.

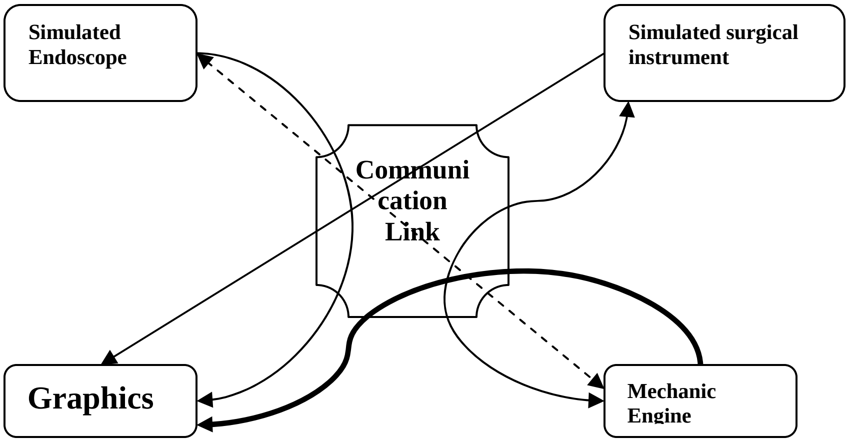
1. The user controls a **virtual instrument**. This instrument device encodes the position of the virtual instrument and feeds back the resulting contact forces. (Input)

2. An **optic device** that encodes the position of the virtual endoscope and hence, the viewpoint of the camera. (Output)

3. A **mechanic engine** performs the intensive computations necessary. (Processing)

4. The **graphics engine** renders the scene as seen through the endoscope. (Processing)

5. These four parts are connected through a **link**. (Communication)



The position of the instrument is transferred both to the mechanic engine, where it may cause contact with the organs. The **graphics engine renders the instrument** as long as it is visible in the scene. It also renders **"special effects"**.

Mechanic reaction forces are propagated back to the **force-feedback** device of the instrument. The state of the deformed organs due to the applied pressure must be communicated to the graphics engine. This has to be drawn in every frame. Finally, the graphics engine must know the **position of the optic device** for defining the camera position. The dashed arrow shows the path taken when the organs collide with the endoscope. The thick arrow shows substantial data transfer.

The modular design of the simulator makes it simple to reconfigure, allowing fast adaptation to user-specific needs. Different versions of the modules have already been developed. This allows integration of different hardware components.

Functional & Performance Requirements

The basic advantage of this new system being proposed allows the simulated organs to behave in an **authentic "bio-mechanic" manner** in which the tissues deform and react in a realistic fashion. Thus we concentrate on the following functions that the system has to do:

- **Construction of a very detailed underlying anatomical model**

  Realistic simulation of the elastic deformation of organs and the resulting forces is possible only if based on a **detailed anatomical model**. The motion and deformation of organs is determined by small structures like ligaments and tendons. This poses a major challenge for the generation of the anatomical model.

  We can use various **image segmentation techniques** for this part. These images are derived from magnetic resonance imaging **(MRI)** and computed tomography **(CT)**. This patient-specific imaging data is exported using proprietary software available. MRI/CT is used because of their **greater soft tissue resolution** than conventional techniques like fluoroscopy and ultrasound.

- **Study of the visual appearance of internal organs**

  This is based on **synthetic organ textures** resulting from analysis of intra-operative images and from **surface visualization** techniques. The main problem here is that one specific virtual patient is not sufficient for training. What we need is a system that allows users to **define arbitrary anatomies** by overriding default attributes of a generic anatomical model. We therefore try to keep all texture-generation methods independent of a specific data set. The goal is to provide a **large texture database** that is grouped into organs and a set of algorithms that allow us to automatically generate texture maps for a selected data set in a reasonable amount of time.

- **Development of a framework for full-scale, 3-D, finite element modeling (FEM) techniques for physically based simulation of elastic abdominal tissue deformation**

  Realistic simulation of tissue behavior is the most challenging area. **Finite element modeling** is the best bet in this scenario even though it uses massive amounts of computing power. FEM is physically based and thus can be easily adapted. In a short summary a body can be subdivided by a finite number of well-defined elements (such as hexahedrons, tetrahedrons and quadrilaterals). Displacements and positions in an element are **interpolated** from discrete nodal values.

  We use short time steps that lead to more realistic motion, but also increase the hunger for computation power.

- **Systematic study of the elastic material properties of living tissue**

  We then focus our attention on the **elastic properties of living tissue**. There is a lot of research going on as to finding the best method that gives us substantial data on the properties over a wide sample of patients.

- **Design of a specialized parallel computer with appropriate FEM algorithms to speed up the expensive FEM calculations to allow real-time performance**

The best way is to build a **scalable parallel computer**. The performance requirements for FEM require a computer with significant processing as well as communication capabilities. The spatial domain will then be decomposed and matched to each processing element (PE).

Interlacing and overlapping communication with the actual calculations allows a maximal utilization of the computer power available without delays caused by communication latencies.

- **Integration of force-feedback devices to provide the necessary haptic feedback for the surgeon**

  Although the tactile information mediated by the surgical instruments during laparoscopic surgery is strongly limited, force feedback is an indispensable component of any realistic simulation environment. During minimally invasive operations haptic information is provided exclusively by mechanical manipulators making feasible the implementation of simulated surgical instruments that provide realistic force feedback based on the technology available today.

  Wired gloves can be worn to gauge the amount of pressure is applied by the surgeon. This information can then be transmitted to the computer. New things such as smell and sound feedback can also be incorporated if deemed necessary.

  We need to find **parallel algorithms** for the necessary FE calculations. Depending on this we need to find out what kind of computer is required. For a detailed simulation a huge amount of computing power is required. Parallel processing and **optimized communication** is required.

  During laparoscopic surgery, the following **four specialized degrees of freedom** of the manipulators are required:

  - The pivoting of providing the entry point of the instrument into the body. This defines a conical workspace described by two angles of tilt.
  - Translation of the surgical instrument into the body.
  - Rotation of the instrument along its longitudinal axis.

Brief Survey of state-of-the-art

The system provides human-like reactions. It allows for reproducibility of actions and helps in training users. Algorithms for realistic simulation of soft-tissues and actions on them can be utilized. Simulation of special effects that occur during simulation like bleeding, cauterization, suction and others also can happen. The system also has the ability to quantify the user’s response in specific situations to assess the surgical proficiency. The output device can be a simple screen. Haptic devices are used for force feedback. There is a real-time interaction between the advanced simulation and the realistically designed tools that the surgeons use. Several companies sell devices that we might need. Immersion and Phantom are the prominent ones. We can build up our own **parallel computer with shared memory** (due to the amount of communication involved).

Conclusion

Many surgical simulation systems have been deployed. Almost all of them have been caught up in the Simulation quality v/s Cost war. With the current advanced hardware and development in computer algorithms we can give our surgeons better tools to practice on. The proposed system is very feasible.

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