Image Guided Surgery Using Virtual Reality

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Abstract : VR technology has been successfully applied to a number of behavioral conditions over the last few years. In the present paper survey on current status of virtual reality technologies in the field of Image Guided Surgery is carried out.

Keywords- Virtual Reality, Image Guided Surgery, Raman System

I. INTRODUCTION

The existing Virtual Reality technology is predominantly vision-based, but in many object-handling applications the feel of an object and the feedback of interaction forces are of primary importance. VR tools and techniques are being developed rapidly in the scientific, engineering, and medical areas.

This technology will directly affect medical practice. Computer simulation will allow physicians to practice surgical procedures in a virtual environment in which there is no risk to patients, and where mistakes can be recognized and rectified immediately by the computer. Procedures can be reviewed from new, insightful perspectives that are not possible in the real world.

Now, collaborators at the Human Interface Technology Laboratory at the University of Washington, along with the University’s Department of Rehabilitation Medicine and the San Francisco Parkinson’s Institute, are using virtual imagery to simulate an effect called kinesia paradox, or the triggering of normal walking by presenting collimated visual cues moving through the patient’s visual field at speeds that emulate normal walking. The combination of image collimation and animation speed reinforces the illusion of space-stabilized visual cues at the patient’s feet. This novel, VR-assisted technology may also prove to be therapeutically useful for other movement disorders.

Image-guided surgery (IGS) fuses medical imaging, computer visualization, and real-time tracking of medical tools to provide the surgeon with a more detailed view of the patient’s anatomy. Current techniques in image-guided surgery rely primarily on visual feedback from the surgical site. In this paper, we address the issue of extending this feedback by adding a sensing modality—Raman spectroscopy—to one of the already successful techniques of image guidance: virtual reality. It is hypothesized that other modalities of information from the surgical/tumor site based on these non-visual (biochemical) aspects will enhance the surgeon’s ability to more completely define resection margins.

Conventional histopathology lacks both the capability for providing immediate feedback and the precision to quantify the extent of disease, particularly in the early stages. Final results usually require 12–24 hours. Even the examination of the more immediate frozen sections require at least 20 minutes from the time the tissue is removed until the time an answer is available. During tumor-removal surgeries (e.g. for brain cancer), this means longer operation times with the patient remaining open.

Raman spectroscopy is a technique capable of detecting normal and abnormal regions of tissue [1]. Its near-real-time analysis and the fact that it does not require sample preparation make it highly suited for in vivo applications. Image guided surgery helps the surgeon position and track instruments (such as a Raman probe) inside the body, making it a natural complement for Raman spectroscopy. Integration of this sensing technology with IGS should help maximize its usefulness for in vivo applications. Thus, this paper investigates the integration of a Raman probe with an image-guided surgery system for enhanced future tissue diagnosis.

II. CURRENT STATUS OF VIRTUAL REALITY TECHNOLOGY

The commercial market for VR, while taking advantage of advances in VR technology at large, is nonetheless contending with the lack of integrated systems and the frequent turnover of equipment suppliers. Over the last few years, VR users in academia and industry have developed different strategies for circumventing these problems. In academic settings, researchers buy peripherals and software from separate companies and configure their own systems to maintain the greatest application versatility. In industry, however, expensive, state of the art VR systems are vertically integrated to address problems peculiar to the industry.

Each solution is either too costly or too risky for most medical organizations. What is required is a VR system tailored to the needs of the medical community.
Unfortunately, few companies offer integrated systems that are applicable to the VR medical market. This situation is likely to change in the next few years as VR-integration companies develop to fill this void. At the same time, the nature of the commercial VR medical market is changing as the price of high performance graphics systems continues to decline. High-resolution graphics monitors are becoming more cost-effective even for markets that rely solely on desktop computers. Technical advances are also occurring in networking, visual photo-realism, tracker latency through predictive algorithms, and variable resolution image generators. Improved database access methods are underway. Hardware advances, such as eye gear that provide an increased field of view with high-resolution, untethered VR systems and inexpensive intuitive input devices, e.g., DataGloves, have lagged behind advances in computational, communications, and display capabilities.

III. SURGICAL TRAINING AND SURGICAL PLANNING

Various projects are underway to utilize VR and imaging technology to plan, simulate, and customize invasive (as well as minimally invasive) surgical procedures. One example of a VR surgical-planning and training system is the computer-based workstation developed by Ciné-Med of Woodbury, Connecticut [McGovern, 1994]. The goal was to develop a realistic, interactive training workstation that helps surgeons make a more seamless transition from surgical simulation to the actual surgical event. Ciné-Med focused on television-controlled endosurgical procedures because of the intensive training required for endosurgery and the adaptability of endosurgery to high quality imaging. Surgeons can gain clinical expertise by training on this highly realistic and functional surgical simulator. Ciné-Med’s computer environment includes life-like virtual organs that react much like their real counterparts, and sophisticated details such as the actual surgical instruments that provide system input/output (I/O). To further enhance training, the simulator allows the instructor to adapt clinical instruction to advance the technical expertise of learners. Surgical anomalies and emergency situations can be replicated to allow practicing surgeons to experiment and gain technical expertise on a wide range of surgical problems using the computer model before using an animal model. Since the steps of the procedure can be repeated and replayed at a later time, the learning environment surpasses other skills-training modalities.

The current prototype simulates the environment of laparoscopic cholecystectomy for use as a surgical training device. Development began with the creation of an accurate anatomic landscape, including the liver, the gallbladder, and related structures. Appropriate surgical instruments are used for the system I/O and inserted into a fiberglass replica of a human torso. Four surgical incisional ports are assigned for three scissors grip instruments and camera zoom control.

The instruments, retrofitted with switching devices, read and relay the opening and closing of the tips, with position trackers located within the simulator. The virtual surgical instruments are graphically generated on a display monitor where they interact with fully textural, anatomically correct, three-dimensional virtual organs. The organs are created as independent objects and conform to object-oriented programming.

To replicate physical properties, each virtual organ must be assigned appropriate values to dictate its reaction when contacted by a virtual surgical instrument. Collision algorithms are established to define when the virtual organ is touched by a virtual surgical instrument. Additionally, with the creation of spontaneous objects resulting from the dissection of a virtual organ, each new object is calculated to have independent physical properties using artificial intelligence (AI) subroutines. Collision algorithms drive the programmed creation of spontaneous objects. To reproduce the patient’s physiological reactions during the surgical procedure, the simulation employs an expert system. This software sub-system generates patient reactions and probable outcomes derived from surgical stimuli, for example, bleeding control, heart rate failure, and, in the extreme, a death outcome. The acceptable value ranges of these factors are programmed to be constantly updated by the expert system while important data is displayed on the monitor. Three-dimensional graphical representation of a patient’s anatomy is a challenge for accurate surgical planning. Technological progress has been seen in the visualization of bone, brain, and soft issue. Heretofore, three-dimensional modeling of soft tissue has been difficult and often inaccurate owing to the intricacies of the internal organ, its vasculature, ducts, volume, and connective tissues. As an extension of this surgical simulator, a functional surgical planning device using VR technology is under development that will enable surgeons to operate on an actual patient, in virtual reality, prior to the actual operation. With the advent of technological advances in anatomic imaging, the parallel development of a surgical planning device incorporating real-time interaction with computer graphics that mimic a patient’s anatomy is possible. Identification of anatomical structures to be modeled constitutes the initial phase for development of the surgical planning device. A spiral CAT scanning device records multiple slices of the anatomy during a single breath inhalation by the patient. Pin-registered layers of the anatomy are thus provided for the computer to read.

IV. BEHAVIORAL EVALUATION AND INTERVENTION

VR technology has been successfully applied to a number of behavioral conditions over the last few years. Among the greatest breakthroughs attained through the use of this technology is the relief of akinesia, a symptom of Parkinsonism wherein a patient has progressively greater
difficulty initiating and sustaining walking. The condition can be mitigated by treatment with drugs such as L-dopa, a precursor of the natural neural transmitters dopamine, but usually not without unwanted side effects. Now, collaborators at the Human Interface Technology Laboratory at the University of Washington, along with the University’s Department of Rehabilitation Medicine and the San Francisco Parkinson's Institute, are using virtual imagery to simulate an effect called kinesia paradoxa, or the triggering of normal walking behavior in akinetic Parkinson’s patients [Weghorst 1994]. Using a commercial, field-multiplexed, “heads-up” video display, the research team has developed an approach that elicits near-normal walking by presenting collimated virtual images of objects and abstract visual cues moving through the patient’s visual field at speeds that emulate normal walking. The combination of image collimation and animation speed reinforces the illusion of space-stabilized visual cues at the patient’s feet. This novel, VR-assisted technology may also prove to be therapeutically useful for other movement disorders.

V. APPROACH OF IGS

In order to evaluate the integration of Raman spectroscopy and image-guided surgery, we developed a system utilizing several hardware and software components. A portable Raman spectrometer was attached to a passively articulated mechanical arm. We also implemented classification algorithms for Raman spectra. The results of the classification are sent to a medical visualization system. Once these systems were integrated together, testing was done with a phantom skull (shown in Figure 1). The skull was filled with various plastic and rubber objects, and CT images were obtained. The entire system was then used to scan objects in the skull, classify the resulting spectral data, and then place markers within our visualization system. Each of the subsystems is described in greater detail below.

A. Tracking Arm

To track the position of a Raman spectrometer, we attached one to a passively articulated arm, an Immersion MicroScribe G2X (shown in Figure). This arm has five degrees of freedom and, based on our previous research [4], provides joint feedback with an accuracy of 0.87 mm. It was chosen because it is simple to use and its tracking accuracy is within acceptable limits. We developed a software application that registers the MicroScribe with patient imaging data (via pair point matching) and tracks the location of its end-effector. The tracking is accomplished by passing the arm’s angular joint feedback through a forward kinematics model of the MicroScribe using Craig’s modified Denavit-Hartenberg (DH) convention. The computed tracking data is relayed in real-time to our visualization system.

B. Raman Spectrometer

An InPhotonics Verax Raman probe (shown in Figure) was affixed to the MicroScribe using a simple clamping system. The end-effector of the MicroScribe was marked to ensure consistent placement, allowing the probe to be detached and reattached. The kinematic model for the MicroScribe was extended by adding an extra transformation from the end-effector to the tip of the Raman probe. This transformation allows the probe to be tracked in our visualization system relative to the skull’s CT scan data.

C. Raman Classification

Many techniques have been developed for the classification of Raman spectra. For our implementation, we used a method based on artificial neural networks, which have been shown to perform well for Raman classification. The final output was the classification of the scanned tissue/material and a percentage indicating the confidence of the neural network.

A variety of preprocessing tasks are performed on the raw Raman spectral data, including background fluorescence subtraction (via adaptive polynomial fitting), median noise filtering, normalization, and peak extraction. Due to the high dimensionality of Raman spectra, we used principle component analysis to select the most significant spectral peaks for algorithm consideration.

D. Visualization

The visualization for our image-guided surgery system is implemented using 3D Slicer, an open-source application for displaying medical data. 3D Slicer provides a virtual reality environment in which various imaging modalities (e.g. CT or MRI data) can be presented. The software
includes the ability to display the locations of objects with respect to 3D models that are derived from segmentation of the medical imaging.

We modified 3D Slicer in several ways to adapt it to our application. First, we developed a TCP/IP interface that receives the tracking data for the MicroScribe and displays its position in the VR environment relative to the medical imaging data. This allows us to track the Raman probe in real-time. Second, we developed a way to place colored markers that indicate tissue/material classification on the medical imaging data. The combination of these modifications enables us to denote the location and classification of tissue/material scanned with the probe in near-real-time.

![Figure 2: A screenshot of our visualization system](image)

### VI. LIMITATIONS OF VR

Several current virtual environment applications in healthcare have problems that limit their effectiveness. Specifically, at least three technical problems limit their actual application. These are as follows:

- **Cost:** Although some attempts have been made to use PC-based virtual reality systems, most of the existing VE’s are based on RISC platforms whose cost is beyond the reach of the average therapist.

- **Lack of reference standards:** Almost all applications in this sector can be considered "one-off" creations tied to a proprietary hardware and software, which have been tuned by a process of trial and error. This makes them difficult to use in contexts other than those in which they were developed.

- **Non-interoperability of system:** Although it is theoretically possible to use a single virtual reality system for many different applications, none of the existing systems can be easily adapted to different tasks. This means that two different departments within the same organization may find themselves having to use two different VR systems because of the difficulty of adapting one single system to their different needs.

### VI. CONCLUSION

The development of methods of electronic communication, clinicians have been using information and communication technologies for the exchange of health-related information. However, the emergence of new shared media, such as the Internet and virtual reality are changing the ways in which people relate, communicate and live. The offered information technologies, the multimodal man-machine interface and a virtual reality technique find more and more wide applications not only in medicine, but also in other areas (service, home assistance, telecommunications, space, etc.). Thus the intelligence of virtual reality and multi-agent technologies will play especially important role.

### REFERENCES