Virtual Tissue Properties

Biomechanical and Physical Modelling of the Handling Characteristics of Tissues and Organs During Surgical Interventions.

Figure 1a: compliance of pig liver and spleen.

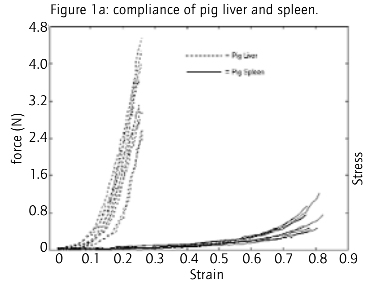


Figure 1b: mathematical model vs experimental data.

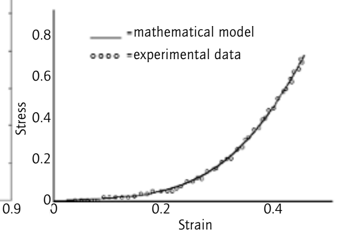


Figure 3: Human liver, 5 patients.

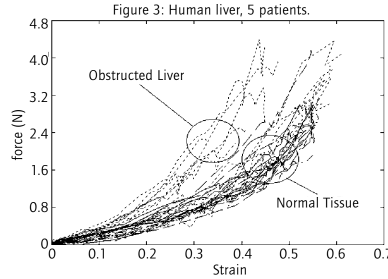
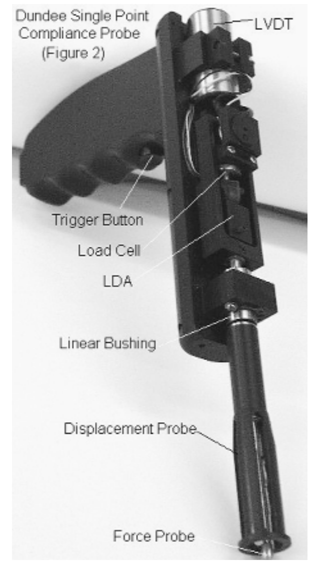


Figure 2



Program Summary

Computer-based simulators offer a promising future for surgical training, treatment planning, and instrument design. These systems must incorporate information about tissue elasticity in order to display realistic deformation and give true tactile feedback during interactions. There is little data about soft tissues properties for abdominal surgery.

The objectives for this project were: (1) to develop testing methods and perform extensive investigations into the biomechanical properties of intra-abdominal soft tissues and organs, and (2) to produce mathematical models to predict soft tissue behavior during specific surgical manipulations.

In Phase 1, indentation tests were performed on excised animal solid organs (liver and spleen) in the laboratory to produce force-strain curves having the same characteristic shape as similar tests on other types of biological tissue. In Figure 1a, the compliance of different solid organs such as spleen and liver is significantly different in the low-strain, physiological range. We modeled tissue behavior for deformation using a large diameter probe (30mm) in Figure 1b. However, boundary conditions for a smaller, more physically realistic probe (4.5mm diameter) were much more complex. Due to the highly non-linear nature of the material, the fact that the incompressibility constraints must hold throughout the whole volume has to be considered, and since the problem involves a large local deformation, there were many difficulties in solving the boundary value problem. The solution was to use 4-point Gaussian quadrature rule, discretising to a square macro-element mesh, in order to remove the possibility of a non-physical deformation occurring in the model.

Phase 2 of the project involved developing instrumentation for in vivo testing on human subjects during surgery to validate the mathematical models using human solid organ data. The Dundee Single Point Compliance Probe (Figure 2) was successfully used in lab trials and on six patients undergoing open surgery. The sensitivity of this instrument (Figure 3) shows data from patients with normal liver tissue compared to that of an obstructed liver, which behaves as a slightly stiffer material. The in vivo human data was found to be very similar to animal ex vivo data at low strains (up to 10%) and we therefore feel that the mathematical models for solid organ deformation will be suitable for in vivo tissue modeling.

Technology Transfer

We are investigating the potential of the single point compliance probe for use in detection of breast lesions and collaborating in the European Minimally Invasive Surgery SIMUlator (MISSIMU) project to provide data for simulators.

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Tissue Force Measurement

Surgical Force Signatures

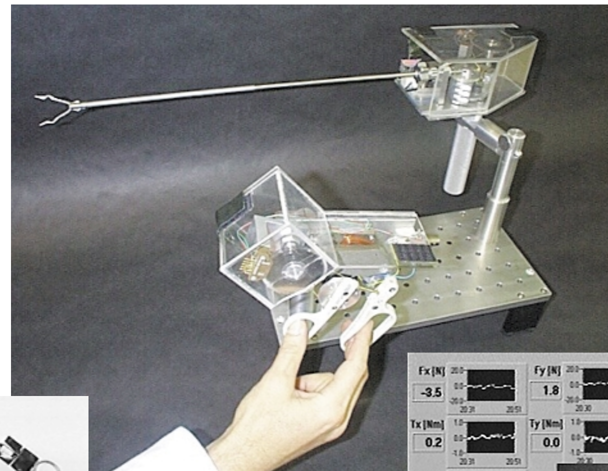

Figure 1

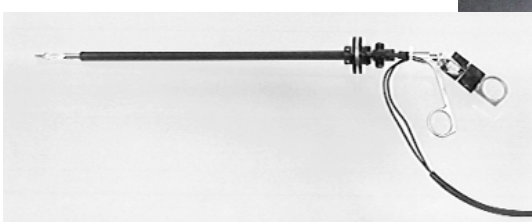

Figure 2

Figure 3

Project Summary
Our project goal was to improve the scientific understanding of the biomechanics and human factors of surgery. The first task involved development of an endoscopic surgical grasper with computer control and a force feedback (haptic) user interface. Experimentally, this device was able to discriminate by palpation between internal organs like normal small bowel, lung, spleen, liver, colon, and stomach. The second task incorporated three axis force/torque sensor into a laparoscopic grasper for measuring forces and torques at the surgeon-hand/tool interface during a standardized surgical procedure. These measurements showed distinct differences between expert and novice surgeons. Novices spent more time performing each maneuver and expended a greater magnitude of forces and torques to perform a task. A custom software package for a simplified use of the computationally intensive Hidden Markov Model analysis was developed for this application. We expect that these studies and those that derive from them will have application to the refinement of telesurgery, clinical endoscopic surgery, surgical training, and research.

Technology Transfer
The current prototype model has generated interest from the biomedical device manufacturing industry and the principal investigator is pursuing possible commercialization opportunities. No application beyond laboratory investigation has been performed at this time.

Figure1: Computer controlled Force feedback endoscopic grasper mounted on its storage base
Figure 2: Instrumented endoscopic grasper—A three axis force/torque sensor implemented into the outer tube in an addition to a force sensor located at the instrument handle
Figure 3: Real-time graphic user interface of force/torque information synchronized with the endoscopic view of the procedure using picture-in-picture mode.

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Haptic Input Device for Telesurgery

The Look and Feel Project: Haptic Interaction for Biomedicine

Figure 1

Figure 2

Project Summary

There is a completely new class of surgical instruments which extend the ability of surgeons beyond the limitations of traditional laparoscopic surgery. These are the computer-enhanced or telesurgery systems, which have the goal of improving the surgeon's ability to perform complex surgical procedures, such as coronary artery bypass grafting, while imparting a minimum of trauma to the patient. This project focused upon the development of increased mobility and sensory feedback for a surgical telerobot (Figure 1) designed to perform minimally invasive procedures. In between the master and slave is a computer with highly sophisticated programming that allows the surgeon to actually feel anything the end effector (Figure 2) touches. The software exactly mimics pressure applied by the surgeon, as well as the resistance encountered by the Falcon's wrist and fingers. The fingers, or end effectors, acquire the resistance of the tissue and the system uses the commercial product PHANToM to provide the sense of touch to the surgeon's fingers. Developed by project team member Akhil Madhani and known as the Black Falcon, the system provides touch, or haptic, feedback to users and a proof-of-concept for several important solutions in telesurgery technology.

Technology Transfer

Aspects of the technology have been licensed by Intuitive Surgical, Inc. of Mountain View, CA, for their commercial product, DaVinci Telesurgery System. Control of the system was accomplished by the use of a haptic interface previously developed at the laboratory and now available commercially as the PHANTOM Haptic Interface from SensAble Technologies, Inc., of Cambridge, MA. The PHANTOM interface was also used by Boston Dynamics, Inc., of Cambridge as a force reflecting user interface to their anastomosis simulator.

Awards

The winner of the $30,000 Lemelson-MIT Award

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3-D Holographic Image Display

High Definition Image Volume Projection Display

Project Summary
Advances in display technologies will provide an entirely new way of interacting with virtual objects in training and simulation. Dimensional Media Associates, Inc., has developed a revolutionary new 3-D display technology—Multiplanar Volumetric Display (MVD). A MVD system creates 3-D images from either polygonal or volumetric computer data in an all solid-state display. The images in the MVD are high resolution and full color and provide all of the 3-D cues normally associated with viewing real objects. These include normal eye accommodation (focusing) and convergence, proper stereopsis, and motion parallax in both the horizontal and vertical directions. The system can create solid textured images, translucent textured images, and wire-frame images at the press of a key. It is completely OpenGL compatible and is currently driven by an SGI workstation, but will soon be extended to a PC platform. The system has no moving parts, uses no lasers, and can be configured as a front-viewed workstation, or as a top-viewed 360° walkaround system. The operational prototype produces 2.8 million, 6 bit grayscale voxels within a 6″ x 6″ x 3″ volume. A system under development will have 13.1 million, 24-bit voxels in a 15″ x 13″ x 9″ volume with and volume rate of 40 Hz.

The MVD is a general purpose high resolution 3-D display system. It has numerous military and civilian applications such as surgical simulation, visualization of medical, scientific and industrial volumetric data, situation awareness, mission planning and military command and control, air traffic control, an interface for remotely operated and autonomous aircraft, computed aided engineering and design, and network visualization. The figure shows a suspended heart in a MVD system in a 360° walkaround configuration. For use as a situation awareness display, the system can depict three-dimensional terrain information, the location and movement of ground, air and space resources, and intelligence information such as the location of hidden bunkers and minefields or opposing artillery emplacements and firing ranges and sight lines.

Technology Transfer
The prototype system has enabled Dimensional Media Associates, Inc. to raise additional development funds from private investors. Initial commercialization will begin with limited sales of prototype units. A further developed commercial system in collaboration with Silicon Graphics will have 18.4 million, 24-bit color voxels at an image rate of 60 Hz.. We will establish OEM licenses with strategic partners that will market the display into specific industries such as military, medical, scientific, computer graphics, and entertainment.

Award
Smithsonian (Call Alan for details)

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Virtual Olfaction

Figure 2

Olfactory Stimuli in Virtual Reality for Medical Training Applications

Figure 1

Project Summary

In order to create the highest illusion of realism in virtual reality simulation environments, all of the senses must be engaged. Under many circumstances, the sense of smell provides additional information, frequently through subliminal cues, that heighten the sense of presence in the environment. To date only three of the senses (vision, audio, and haptics) have been incorporated into virtual reality training systems. This project is the first effort to develop both mechanical and corresponding virtual display systems for the sense of smell. The goal is to heighten the sense of realism for soldiers and medics in simulation training by adding vivid odors to the virtual environments.

In order to present the various smells to the individual, a portable device (Figure 1) was constructed that would emit a discrete odor in a very short period of time in response to the given stimulus in the virtual environment. Although the prototype is bulky, it can be worn in a backpack while the individual walks about a virtual environment. Figure 2 depicts a virtual accident scene with casualties. The arrows indicate the direction of the breeze. As the user approaches specific sites in the scene, various odors such as blood, garbage, spilled gasoline, and smoke are introduced into the virtual environment.

Technology Transfer

The prototype is complete and commercialization efforts are under way for partnerships or licensure. To date, the response to the application need appears to be minimal and limited to research organizations.

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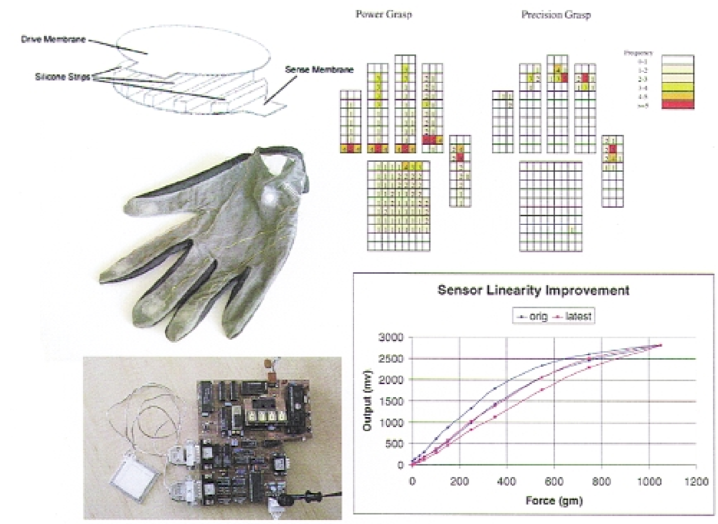
Tactile Sensor Device

Conformable Tactile Sensor for Surgical Data Acquisition

Project Summary

Tactile sensation is crucial to surgical tasks in surgical robotic systems as well as training devices using virtual reality simulators. Pressure Profile Systems, Inc., designs, develops, and manufactures high performance multi-element pressure and tactile sensing systems. The core technology is a variable capacitance sensor which provides numerous advantages over resistance-based sensors, including: higher sensitivity, more repeatable and stable output, reduced wear and aging effects, wider range of tailor-able force sensitivity, and better linearity.



Upper left, single tactile sensor element configuration; upper right, grasp study for assessing placement of tactile sensors; mid left, prototype tactile glove for mouse ergonomic study; lower left, USB micro-controller prototype; lower right, performance output of the tactile sensor element.

Development of the Conformable Tactile Sensor (CTS) technology is a tactile glove that provides pressure contact information for surgical data acquisition by conforming to complexly curved surfaces such as the human hand. Development of a Motility Visualization System for the NIH provides esophageal muscle contraction information of a person swallowing. The CTS Technology provides 24-32 sensor elements on a gastrointestinal catheter rather than the 3-4 elements that are currently available.

Technology Transfer

Pressure Profile Systems, Inc., received an Army SBIR contract for development of a Head Pressure Analysis System that provides fit, comfort, and seal information for head gear such as gas masks, helmets, goggles, etc. Efforts are focused on capitalization and industrial marketing to transition PPS from government contractor to commercial sales focused company.

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"Medical technology is neutral, it is neither good or evil. It is up to us to breathe moral and ethical life into it . . . And then apply it with compassion and empathy."

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