Virtual Reality in Medicine

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Overview of Presentation

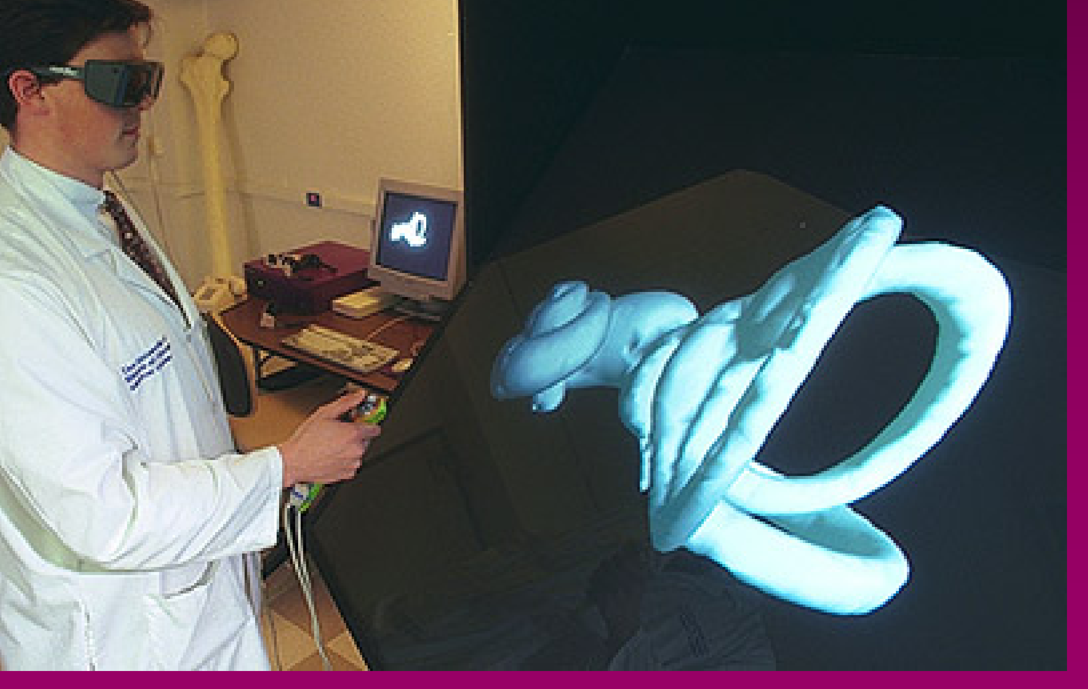
- Medical VR applications:
  - Visualization (virtual endoscopy, bronchoscopy, colonoscopy)
  - Computer assisted surgery (training, planning, rehearsal, and delivery)
  - Radiotherapy planning
  - Dentistry
  - Rehabilitation and therapy
  - Telemedicine
  - Education (teaching, training, determining level of skill)
- Supporting VR research
  - Human-machine interfaces (in particular haptic interfaces)
  - Biological tissue modeling techniques

Medical Visualization

- Visualization in useful in several medical areas:
  - 3-D stereo visualization of anatomical structures
  - 3-D data fusion of multiple imaging modalities
  - virtual endoscopy
  - visualization of individual patient anatomy for surgical planning and rehearsal
  - visualization for image guided surgery procedures
  - visualization of anatomy in radiation therapy planning

3-D Stereo Visualization

- Univ. of Illinois Chicago, School of Biomedical and Health Information Sciences
- ImmersaDesk system for temporal bone visualization



Visible Human Project

- A project of the US National Library of Medicine
- Data is available free of charge
- Visible Human data has been used in many projects as a test data set
- 3D visualizations of various anatomical parts have been used for education of medical students
- 3D anatomical models have been developed using the data
- Visible Human project has inspired several similar Visible x projects

Fetus Visualization

- Univ. of North Carolina at Chapel Hill
- A VR system is developed for visualization of a fetus in a pregnant woman's abdomen
- The ultrasound image of the fetus is superimposed on the video image of the woman's abdomen
- The system can be used for pregnancy check-ups

Classical Endoscopy

- In classical endoscopy an endoscope is inserted into the patient to examine the internal organs such as colon, bronchial tubes, etc.
- An optical system is used by physician to view interior of the body
- Advantages of clasical endoscopy:
  - optical viewing system provides look of the tissue surface which is important diagnostic information
- Disadvantages of clasical endoscopy:
  - possibility of injury
  - endoscope cannot pass through the colon walls

Virtual Endoscopy

- Virtual endoscopy procedure has several steps:
  - 3D imaging of the organ of interest (e.g using CT, MRI)
  - 3D preprocessing (interpolation, registration)
  - 3D image analysis to create model of the desired anatomical structures (segmentation)
  - Computation of the 3D camera-target path for automatic fly-through or manual path selection
  - Rendering of multiple views along the computed path to create the animation (either surface or volume rendering)
- First VE procedures published in 1995 for virtual colonoscopy

Virtual Endoscopy Features

- Advantages:
  - there are no restrictions on the movement of virtual endoscope (it can be moved anywhere through the body)
  - avoids insertion of an instrument into a natural body opening or minimally invasive opening
  - no hospitalization
- Disadvantage:
  - current virtual endoscopy techniques do not reveal the look of the tissue surface (3D imaging techniques do not reveal

Virtual Endoscopy Applications

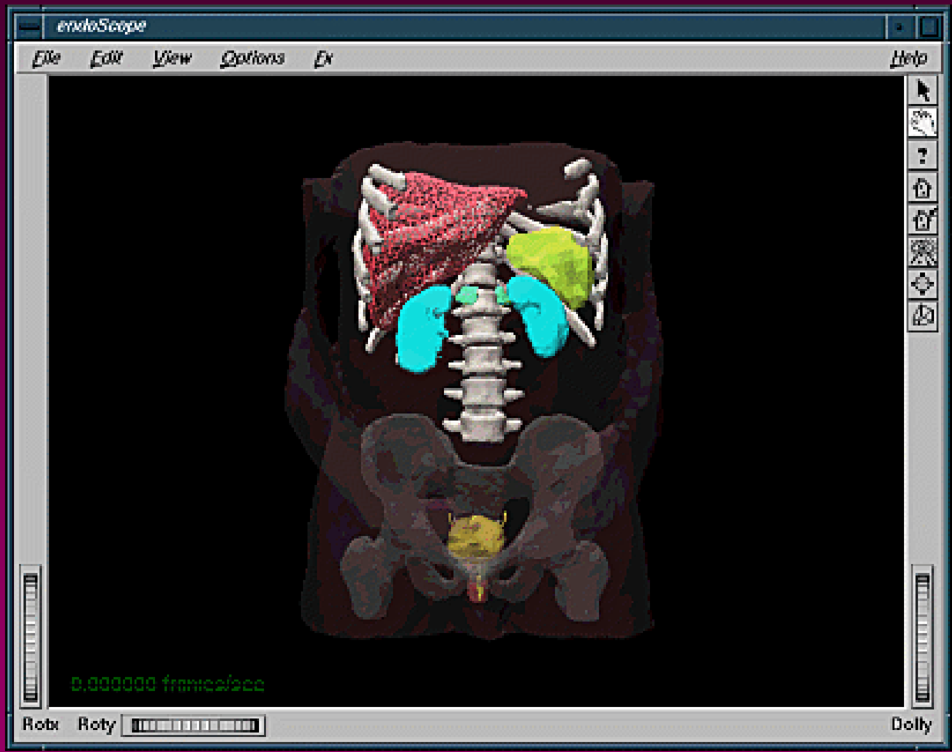
- Easy for large size organs: bronchial tree, renal system, pancreatico-biliary tree, uterus, cerebro-ventricular system, spinal canal, major joints
- Special attention required for: GI tract, colon, vascular tree (contrast), temporal bone and inner ear (high resolution), and heart (motion)
- Previous work
  - Virtual colonoscopy (Vining, Kaufman)
  - Carotid arteries (Lorensen)
  - 3-D organ visualizations (Robb)
  - Visualizations for stereotactic neurosurgery (Jolesz and Kikinis)

Recent VE Projects

- endoScope - A VR tool for anatomical fly-through
- Virtual endoscopy using CT and perspective volume rendering
- Virtual colonoscopy at SUNY Stony Brook

endoScope - A VR Tool

- EndoScope is a Motif/Inventor based model viewer that runs on SGI workstations
- Developed by Biomedical Imaging Resource at Mayo Clinic

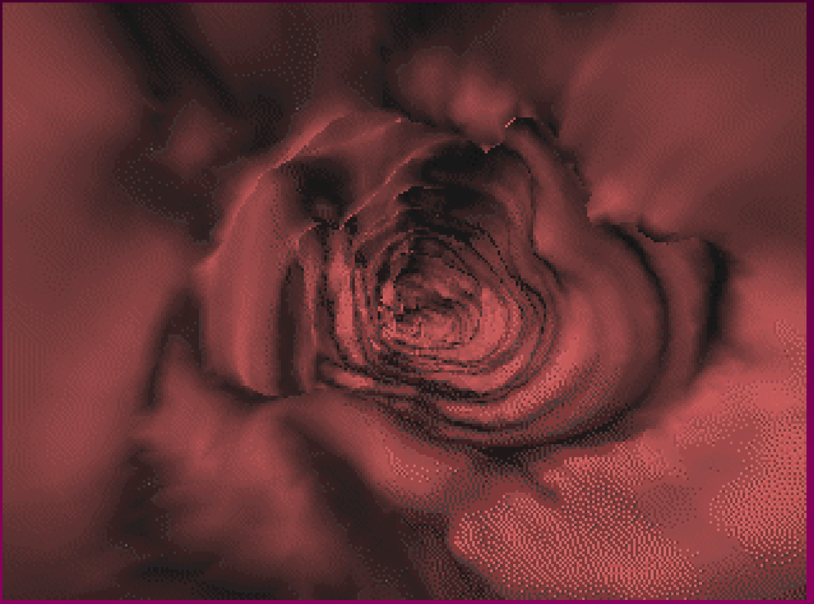


VE using CT and Perspective Volume Rendering

- Shahidi et al., Vital Images, Inc.
- Used CT images for perspective volume and surface rendering visualization of tube-like structures:
  - detection and studies of aneurysms in the circle of Willis
  - studies of thoracic aorta aneurysms
  - assessment of bronchial anastamoses
  - detection of polyps in colonic lumen
- Key framing technique is used for path selection (key frames were manually selected and the computer interpolates position of additional frames and computes views)

Virtual colonoscopy at SUNY Stony Brook

- Based on VolVis volume visualization system developed by Arie Kaufman at SUNY Stony Brook
- Used on Visible Human data and real patients
- Used for detection of polyps in the human colon



Virtual bronchoscopy

- FER, Univ. of Zagreb
- Visualization of bronchial tubes

Virtual Reality for Surgery

- Surgical training
  - for education of surgeons
- Surgical planning
  - modeling and visualization of individual anatomical models
  - abdominal surgery planning
- Surgical rehearsal
  - for rehearsal of complex surgical procedures
- Surgical delivery
  - assists surgeons during surgical procedures
  - increases speed and accuracy of surgical procedures
  - reduces patient trauma and risks

Surgical Training

- Statistical studies show that doctors are more likely to make errors during their first several to few dozen surgical procedures
- There is a shortage of cadavers for medical research
- It is helpful if medical training can be performed using a realistic imitation of a human body inside the computer
- Training is used for:
  - laparoscopic surgery (minimally invasive surgery)
  - heart catheterization simulation
  - open surgery

Virtual Body vs. Cadaver

- Training on cadavers has several drawbacks:
  - if trainee cuts a nerve or a blood vessel in a cadaver nothing will happen
  - no action can be reversed on cadavers (what is cut is cut)
  - dead tissue is harder, color is changed, arteries do not pulsate
- Advantages of computer simulations:
  - procedures can be repeated many times with no damage to virtual body
  - virtual body does not have to be dead - many functions can be simulated for realistic visualizations
  - organs can be made transparent and modeled

Surgical Training Projects

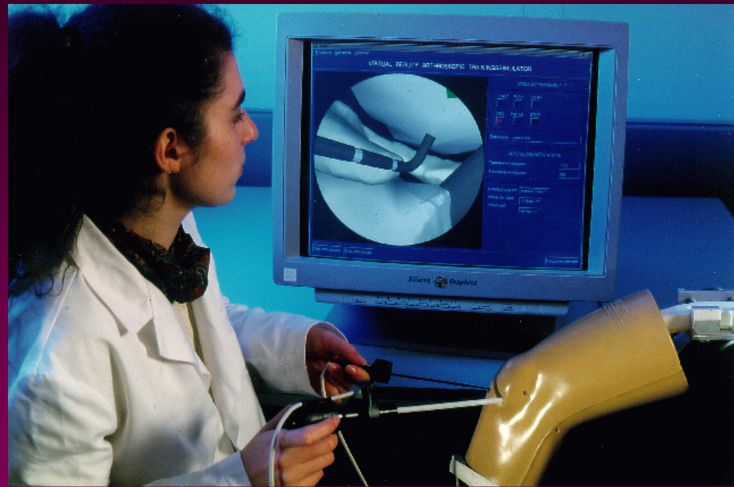
- A virtual reality based training system for minimally invasive surgery (MIS)
- Fraunhofer Institute medical training simulator
- MIS training at EPFL, Laussane
- Eye surgery simulator at Georgia Tech
- High Techsplantations, Inc. simulators

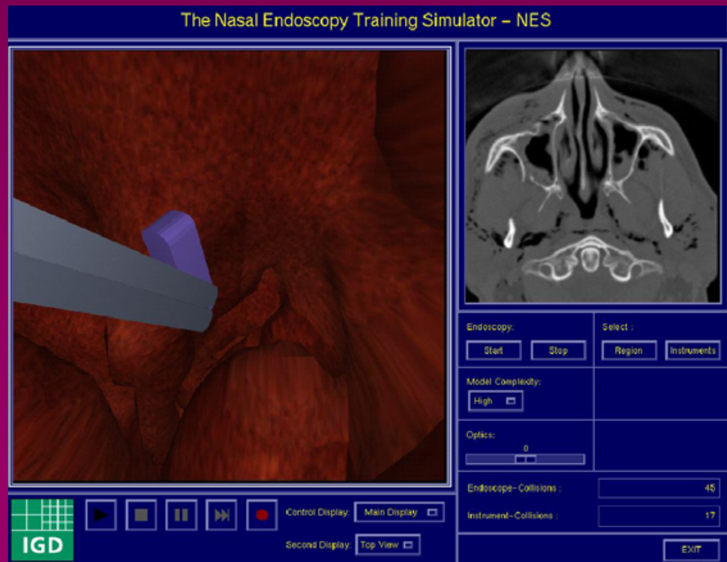
VR Training for MIS

- Medical Robotics Group at UC Berkeley
- Learning laparoscopic techniques are more difficult then open surgery techniques (no tactile information, indirect field of view, difficult training for hand-eye coordination)
- Training is either on animals or in the operating room
- Finite-element models are developed for modeling of soft tissue behavior
- Visual and haptic displays are developed for creation of a realistic surgical tools (with force feedback and tactile information)

Fraunhofer Institute Simulators

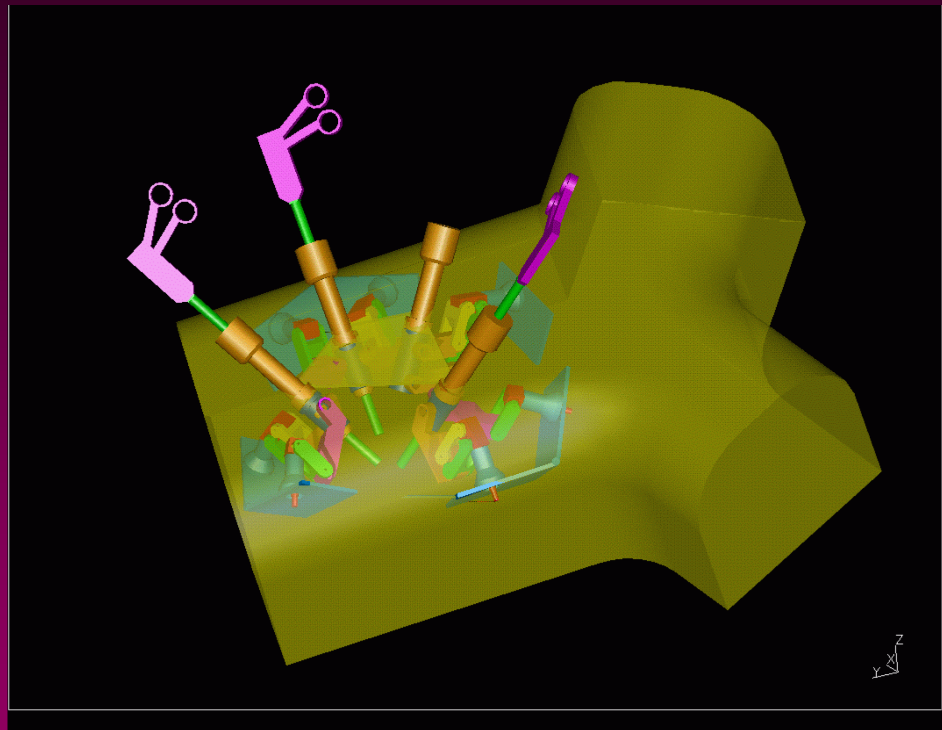
- Fraunhofer Institute medical training simulators
- The arthroscopy training simulator
- Nasal endoscopy simulator
- The trainee is able to practice techniques before facing a real patient

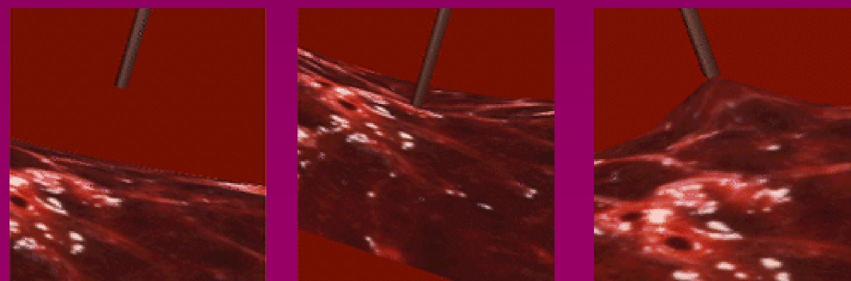




MIS Training at EPFL

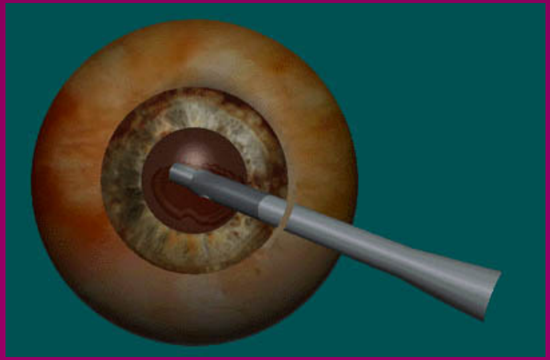
- Group for surgical robotics and instrumentation, Swiss
- Gastro-intestinal organ modeled and tissue properties simulated (pushing, pulling)
- Force feedback generated for realistic simulation





Eye Surgery Simulator

- Interactive Media Technology Center at Georgia Tech
- Eye surgery simulator for:
  - education and training of medical students
  - training of surgeons to cope with emergencies
- Simulator provides force feedback information for more realistic simulation of tissue cutting
- Simulation of the tissue includes elasticity of the eye surface tissue before a cut is made



High Techsplantations

- HT Medical is a company that developed “virtual abdomen” for laparoscopic simulation of abdominal surgery
- HT also simulated angioplasty procedure
  - the trainee uses a simulated balloon catheter
  - various complications included such as rupture of the balloon or the coronary vessel
  - a special catheter simulator is designed that has force feedback and position sensors

Surgical Planning

- Creation and validation of patient specific models for prostate surgery planning using virtual reality
- Virtual tape measure for 3D measurements
- VR Assisted Surgery Program (VRASP), Mayo Clinic

Patient-Specific Surgical Planning

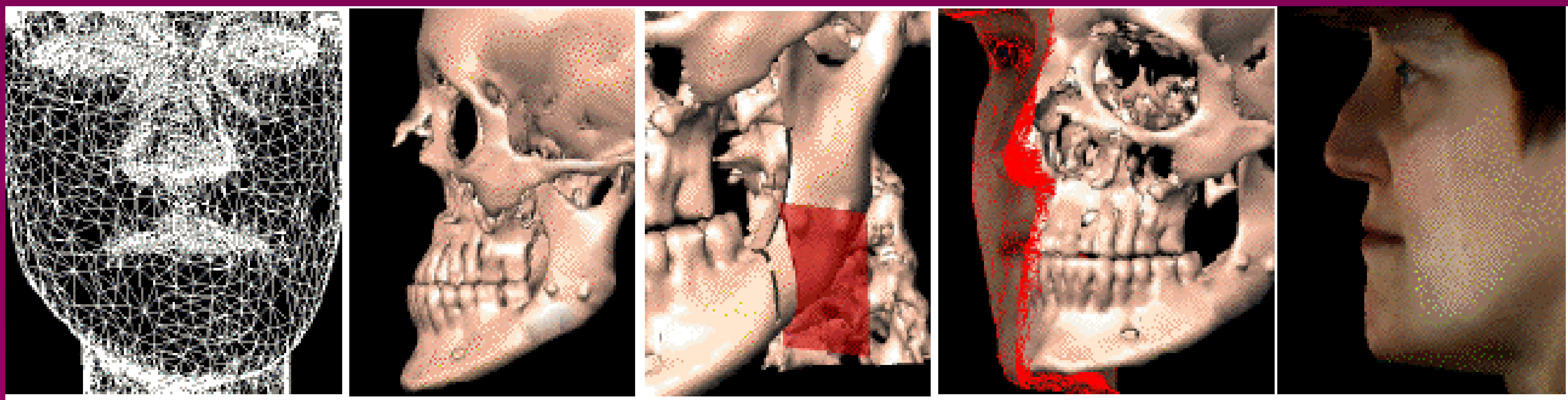
- Kay et al., Mayo Clinic
- Prostate surgery for cancer removal can lead to morbidity because of complex and variable individual anatomy
- A procedure is developed to extract individual patient anatomy from MRI pelvic scan data
- A 3D model of prostate gland is used for visualization and planning of radical prostatectomies
- The procedure uses Analyze software

Virtual Tape Measure

- Kim et al., Univ. of Toronto, Canada
- A measuring tool is developed to be used with a surgical operating microscope
- Stereo images of the surgical field are combined with computer generated stereo images to create a virtual tape measure
- The augmented reality display allows accurate measurements to be made between any two points in the surgical field of view
- Reported accuracy of 0.2 to 0.7 mm

Craniofacial Surgery Simulation

- Erlangen Institute, Germany
- In craniofacial surgery it is important to plan and predict the outcome of surgical intervention
- The face can be visualized after reconstructive plastic surgery



VRASP

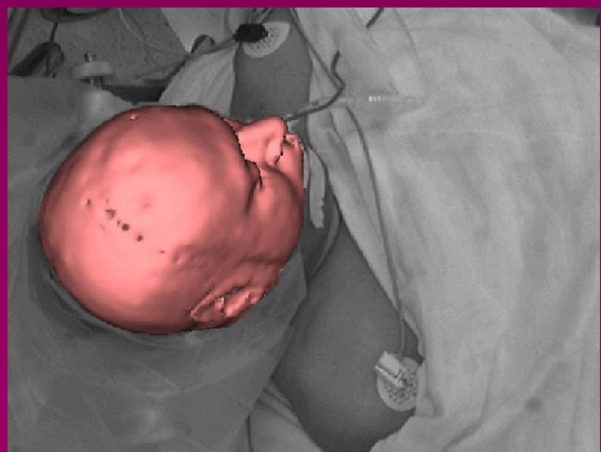
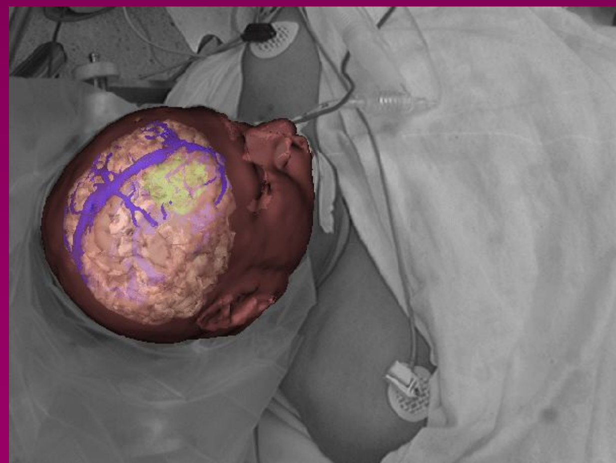
- R. Robb, Biomedical Imaging Resource, Mayo Clinic
- VR Assisted Surgery Planning (VRASP) is a project at BIR
- VRASP is a system to assist surgeons
- BIR has developed Analyze medical image analysis software
- surgery planning
- surgery rehearsal
- endoScope - a tool for anatomic fly throughs

Computer Assisted Surgery

- Augmented reality for surgery
- Augmented reality in neurosurgery
- Arthroscopic surgery of the knee
- Augmented reality in ear nose throat (ENT) surgery
- Augmented reality for needle biopsy of the breast with helmet mounted display

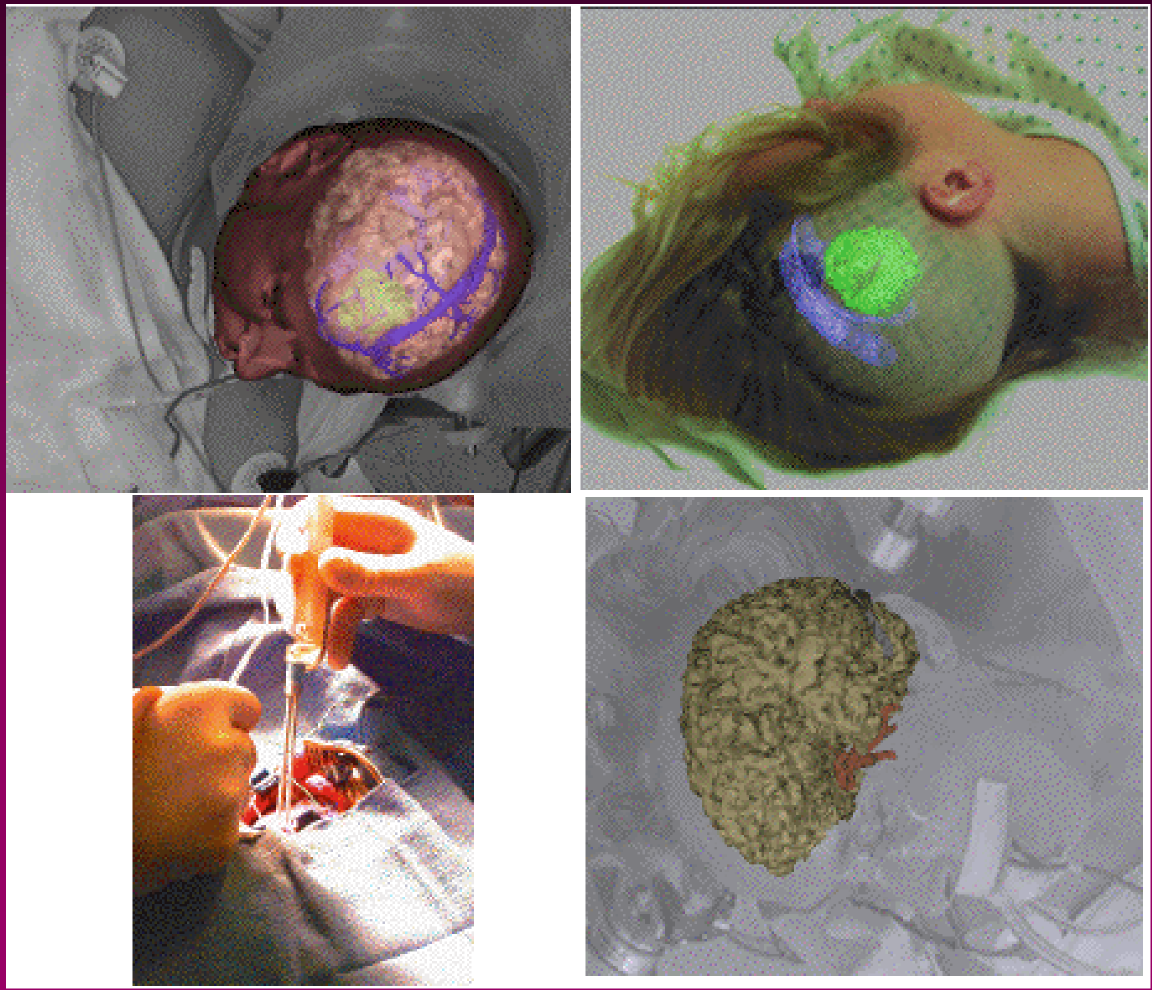
Augmented Reality for Surgery

- Julesz, Harward Medical School
- Augmented reality visualization has three phases:
  1. 3D laser scanning of the patient's head surface
  2. 3D registration of the scanned and imaged surface
  3. Augmented reality display of tumor (green)

Augmented Reality in Neurosurgery

- Harvard Medical School
- Combined neurosurgery planning and augmented reality



Arthroscopic Knee Surgery

- Medical Media Systems, Inc. has developed a system for arthroscopic surgery of the knee
- The procedure has two steps:
  - MRI scan of the knee is taken first
  - A 3D reconstruction of the MRI knee scan is superimposed on the video image of the knee
- The system shortens the surgical procedure duration and improves the surgeon’s orientation

Augmented Reality in ENT Surgery

- ARTMA, Inc. Virtual Patient System uses augmented reality for ENT endoscopic surgery
- The system fuses computer generated images with endoscopic image in real time
- Surgical instruments have 3D tracking sensors
- Instrument position is superimposed on the video image and CT image of the patient head
- The system provides guidance according to the surgically planned trajectory

Augmented Reality for Needle Biopsy of the Breast

- Fuchs et al., Univ. of North Carolina at Chapel Hill
- Ultrasound-guided needle biopsy of the breast
- Conventionally, US image is viewed on a separate monitor and a difficult coordination between the 2D image and the 3D needle position must be done
- In this system the physician is guided by the ultrasound image superimposed on the patient image in a see-through HMD
- Biopsy needle and physician’s head are tracked
- Advantages: reduce time for procedure, training time, greater accuracy, reduced trauma for the patient

Distributed VR for Medicine

- In a distributed VR system several users (e.g. surgeons) share a common virtual environment (e.g. virtual patient in surgery simulation) and act in it
- The users can:
  - cooperate (e.g. edit the same virtual object)
  - or collaborate (e.g. work in parallel on different objects)
- The users are typically interconnected by means of a local or a wide area network
- The main problem in distributed VR is updating the virtual environment to reflect the actions of users

Distributed VR Systems

- Most distributed VR systems are developed for military applications such as multi-user simulations with several hundreds of users (e.g. NPSNET)
- This imposes critical requirements on the computer network and requires use of special protocols (multicast TCP/IP) to reduce network traffic
- Medical applications typically require smaller number of participants

Radiotherapy Planning

- Alakuijala et al., Finland
- Developed a method for radiotherapy treatment planning called “Beam’s Light View”
- The method provides a visualization of the radiation field geometry which can be adjusted in real-time
- The renderings are produced from the viewpoint of radiation beam source
- The field geometry on patient surface is shown

Therapeutic and Rehabilitation

- Phobia desensitization - spider phobia, fear of height, fear of flying
- Pain control for burn patients
- Parkinson´s disease
- VREPAR project
- Improving quality of life for people with disabilities

Phobia Desensitization

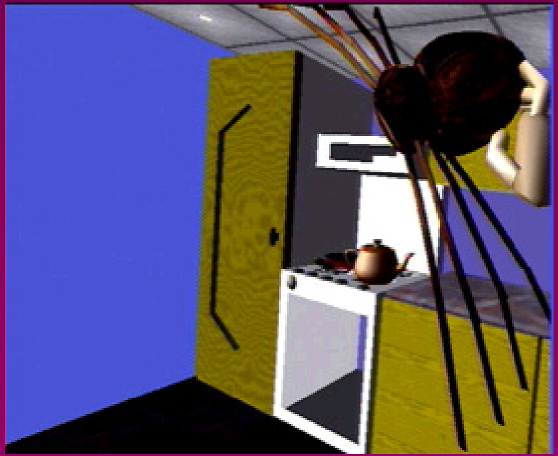
- Fear of heights, fear of flying, spider phobia
- Exposure therapy consists of exposing the subject to anxiety producing stimuli while allowing the anxiety to attenuate
- Patient therapy sessions begin with less threatening situations and then go to more anxiety producing situations
- VR sytem is used for visualizations required to put patient e.g. on the top of a ten-floor building

Phobia Projects

- GA Tech GVU Center Virtual Reality Exposure Therapy project
- Demonstrated effectiveness
- Advantages:
  - cost effective
  - effective therapy
  - patient acceptance
  - suitable for network delivery (telemedicine)

Spider Phobia Desensitization

- Univ. of Washington Human Interface Technology Lab
- VE environment designed that contains virtual spiders (a large brown spider with fur and a small one were used
- Patients are encouraged to pick up spiders with their virtual hands
- Spiders are unexpectedly dropped of the ceiling, patient could pull the spider legs off



Acrophobia Project

- Univ. of Michigan
- Balcony view from high floors are generated
- The patient gradually watches the environment from higher and higher viewpoints
- A multi-session therapy cures the acrophobia patient

Pain Control

- Univ. of Washington Human Interface Technology Lab
- Pain control for burn patients (the worst pain is during dressing changes)
- Pain requires conscious attention
- VR simulations are exceptionally attention grabbing
- e.g. dentists use distraction with their patients and children viewing cartoons through TV glasses experience less pain and fear
- experiments showed less pain ratings while patients were in a virtual environment

Parkinson's Project

- Univ. of Washington Human Interface Technology Lab
- Many people with Parkinson's disease experience difficulty in walking, a condition called akinesia
- Akinesia is a primary symptom of Parkinson's disease
- VR system is used to trigger normal walking behavior in Parkinson's patients by putting obstacles at patient's feet and objects moving through the visual field

VREPAR Project

- European DGXIII HC-1053 project
- Institutions involved: Centro Auxologico Italiano (IT), IBM South Europe Middle East Africa (IT), Instituto Nazionale Neurologico C. Besta (IT), Ruhr Universität Bochum (DE), University of Reading (UK), University of Southampton (UK).
- Use of VR in:
  - eating disorders
  - stroke disorders
  - movement disorders

Improving Quality of Life

- Greenleaf Medical Systems has developed a virtual environment for exploration in a wheelchair
  - People who are confined to a wheelchair can operate a telephone, dance in a virtual world, or practice some sports
- Another example is a system for a quadriplegic people based on an eye tracking device to control and interact with outside world
- The third use of VR is for helping visually impaired people by providing vision enhancements (Johns Hopkins)

Gesture Control System

- Gesture control system is a system based on the DataGlove which recognizes different hand gestures
- Depending on a hand gesture the system can execute certain actions
- Another system called GloveTalker speaks for the user and is controlled by hand gestures that are recognizes by the DataGlove
- The speech is generated by a computer controlled voice synthesis system

Cognitive Deficits

- Pugnetti, et al. have investigated the use of VR for testing of cognitive deficits
- A VR system is used for a navigation-based simulation where patients or normal people are tested using complex cognitive activities
- The performance of the tested subjects was measured and analyzed for the final assessment of the state of the cognitive sytem

Functional Movement Analysis

- A number of VR systems have been developed for measurement and analysis of motor skills
- An example of such applications are DataGlove-based systems for measurement of hand impairment
- Such systems measure strength, sensation, range of motion, and structure
- Example projects:
  - EVAL - a system for analysis of hands and upper extremities
  - WristSystem is designed for measurement of dynamic properties of upper extremities

Telemedicine and Virtual Reality

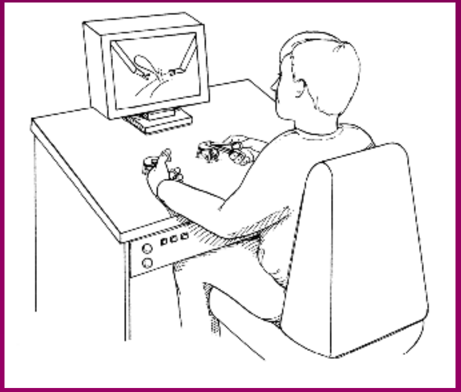
- Telemedicine attempts to break the distance barrier between the provider and the patient in health-care delivery
- Virtual reality is able to simulate physical non-existent or remote environments and is can therefore be applied to telemedicine
- Physicians can have VR produced copy of a remote environment including the patient at their physical location

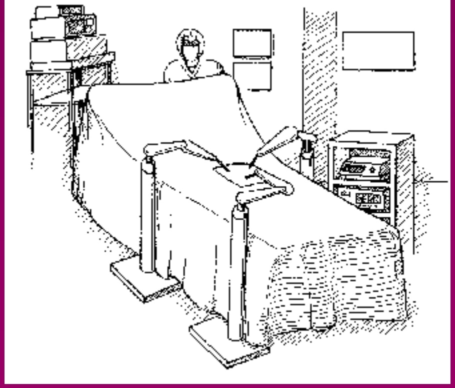
Telemedicine VR Applications

- Telesurgery
- Control of antropomorphic teleoperator fingers
- Telemedicine at US Department of Defense

Telesurgery Research

- Telesurgery is a telepresence application in medicine where the surgeon and the patient are at different locations
- The sketches below show the telesurgery concept currently under development at the Medical Robotics Lab at UC Berkeley





Telesurgery Applications

- Injured in accidents have better chances if they can be operated at the scene of accident by a surgeon from a local hospital
- Wounded soldiers can be operated on the battlefield by a surgeon who can be located elsewhere
- Patients who are too ill or injured to be transported to a hospital may be operated remotely
- There is a need for a surgeon specialist who is located at some distance

SRI Telesurgery System

- SRI International Green Telepresence Surgery System is developed to allow surgeons to act in battlefield operations from sites distant from the front battle line
- The system consists of the remote operative site and a surgical workstation that includes 3-D vision, dexterous precision surgical instrument manipulation, and input of force feedback sensory information
- The surgeon operates in a virtual world and a robot on the battlefield reproduces the surgeons's actions

Control of Anthropomorphic Teleoperator Fingers

- Gupta and Reddy, Univ. of Akron, USA
- Motivation: data gloves have large errors and exo-skeletal devices are cumbersome
- Used biological signals (skin surface EMG) to control a computer model of a two finger teleoperator
- Study revealed a linear relationship between the RMS EMG and the extension of the finger model
- The RMS error in the system was 0.22-2.75 degrees
- Demonstrated that surface EMG can be used for a biocontrol for teleoperators and in VR applications

VR in Education

- There are numerous medical education resources available on Internet
- Educational use of virtual reality includes:
  - 3-D visualization for display of complex anatomical structures
  - fly-through visualizations of organs for study of anatomy
  - pre-defined routes and interactive exploration routes
  - integration of 3-D structural information with multimedia contents

Educational Projects

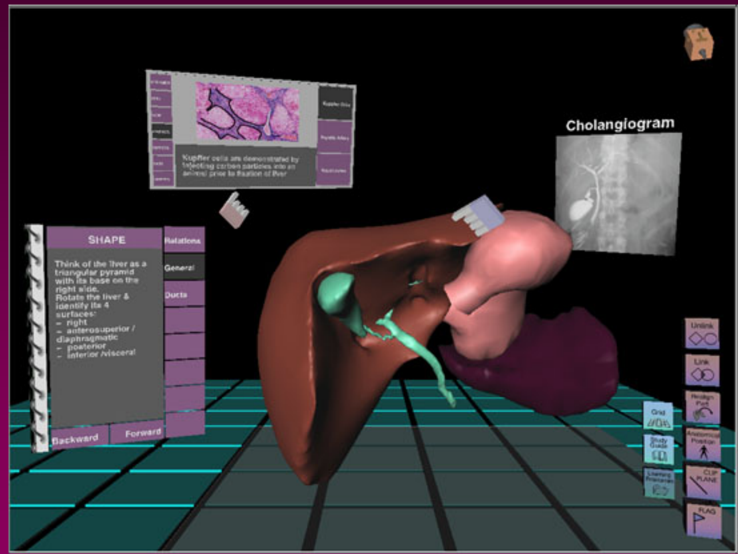
- Some examples are:
  - Virtual Hospital
  - Medical education at UCSD
  - Medical education at Fraunhofer Institute

Virtual Hospital

- Univ. of Iowa project of virtual medical community
- Project has virtual health sciences college, library, hospitals, children’s hospital, clinics, and medical curriculum
- Available on the WWW (http://www.vh.org)
- 2,500,000 hits per month
- Resources for healthcare providers and patients
- Resources for medical students (350 books, multimedia textbooks, patient simulations, journals, continuing education)

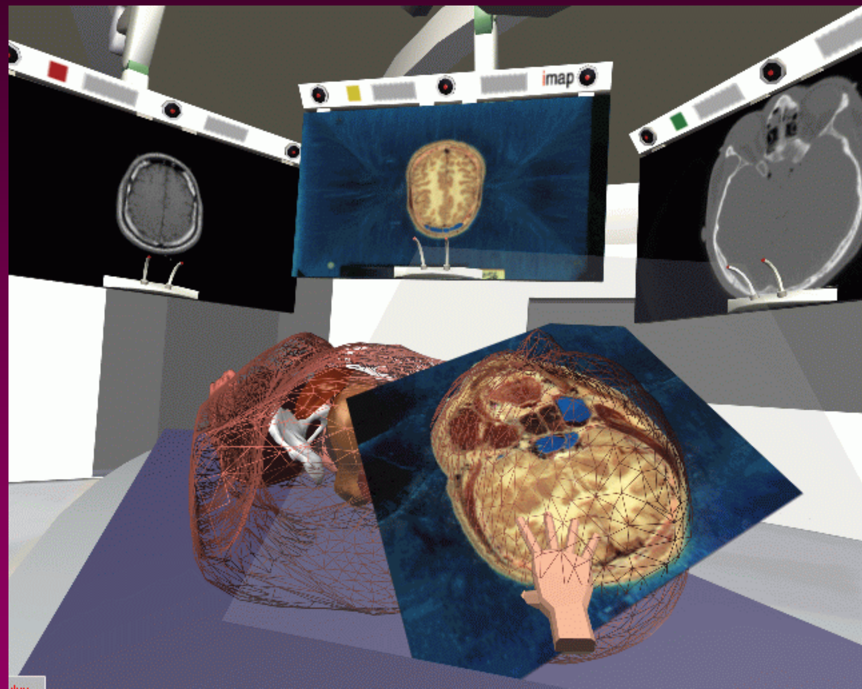
Medical Education at UCSD

- UCSD Applied Technologies Lab project on VR-multimedia system for education of medical students (anatomy)
- UCSD Virtual Anatomy World
- Anatomic structures are linked to supporting multimedia contents to provide VR-MM anatomy lessons



Medical Education at Fraunhofer Institute

- Fraunhofer Institute
- Virtual anatomy system for medical students
- Virtual patient
- Students are able to understand complex interrelationships of anatomical structures



Human-Machine Interfaces

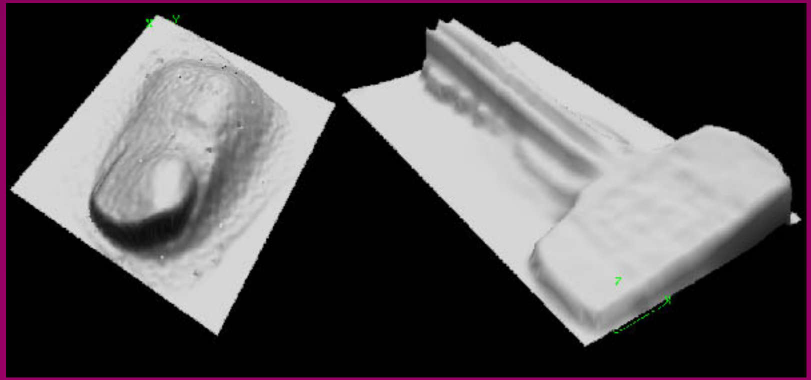
- Force propagation models in laparoscopic tools and trainers
- Remote palpation simulators
- Human machine interfaces for minimally invasive surgery
- Microtactile sensors and displays
- Force feedback devices
- Cyberpathology (physiological and psychological effects of VR interfaces: sickness, adaptation, and presence)

Force Propagation Models

- Payandeh, Simon Fraser Univ., Canada
- Attempts to solve the problem of lack of tactile perception in laparoscopic surgical tools
- Solutions: force reflective graspers
- Models for force propagation are proposed that enable realistic simulation of reflection of the sense of the grasping force

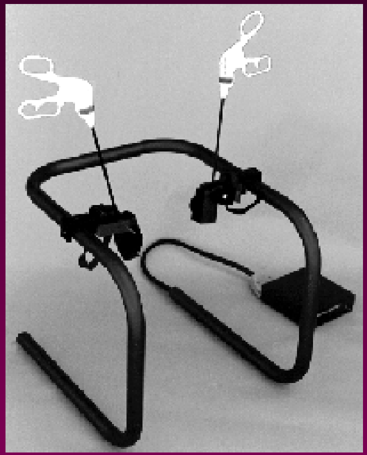
Remote Palpation Simulator

- Interactive Technology Media Center at Georgia Tech
- The idea is to allow doctors to examine patients at a remote location
- IMTC developed a haptic lens - a sensor that measures 3D surface under a specific pressure
- The device is pressed against an object and 3D surfaces, deformed under the pressure, are recorded in real-time



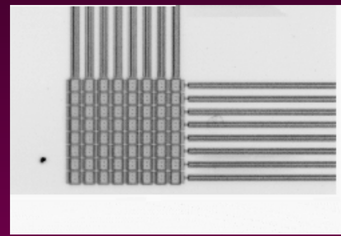
Laparoscopic Interfaces

- Immersion Corp. devices for minimally invasive surgery simulators
- Offers tracking in 5 degrees of freedom (left-right, up-down, in-out, rotation around axis, open-close)
- Version with and without force-feedback are available
- Price range: up to $8,000



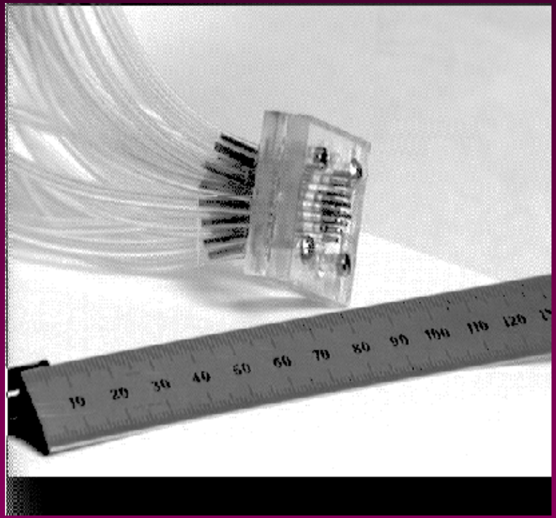
Microtactile Sensor

- Medical Robotics group at UC Berkeley
- Developed tactile sensor arrays to be mounted on a laparoscopic manipulator
  - each sensor consists of 8x8 array of capacitive sensor cells covered by a rubber layer that serves as a low-pass filter
  - when pressure is applied resulting deformation causes changes in capacity



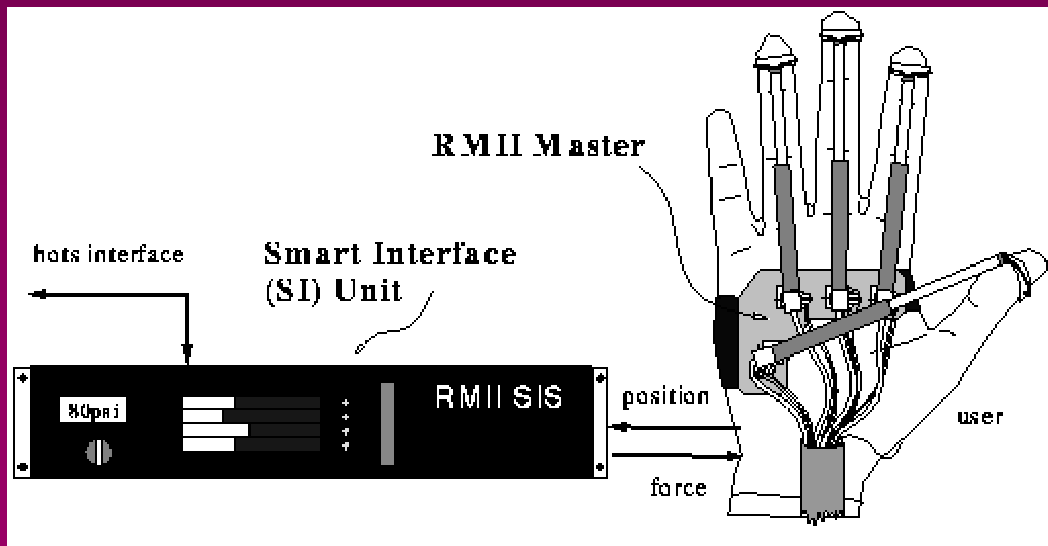
Microtactile Display

- Medical Robotics group at UC Berkeley
- Developed 5x5 pneumatic tactile display system
- Has 3 bits of force resolution
- 3 dB point at 8 Hz
- 3 mm spacing between the centers of pins
- Maximum force 0.3 N per element



Force Feedback Devices

- Rutgers University, Rutgers Master II
- Reads hand gestures (hand-master)
- Displays forces (haptic display)
- Four fingers in real time



Sensors and Devices for MIS

- Scilingo et al., Univ. of Pisa, Italy
- Designed a sensorization system to acquire:
  - information about the force exerted on the tissue
  - induced deformation of the tissue
- The measured data is displayed on the laparoscopic monitor or on a separate display
- Tactile display replicates behavior of surgical tissues
- In addition, a non-linear model and an identification algorithm are used to extract rheological parameters of the tissue

Cyberpathology

- Studies safety issues and possible side-effects of VR applications
- Cyberpathology are all of the adverse reactions to VR usage:
  - physical pathologies
  - cybersickness

Physical Pathologies

- Injuries that have direct impact on the physical state of the body and include repetitive stress injury and immersion injuries, and transmittable diseases
- Repetitive stress injury results of extended VR use (e.g. joystick use, “firing” button use, and keyboard use)
- Immersion injury is any injury while the user is in the virtual world (running in reference to the virtual world instead to true reality)
- Transmittable diseases are possible because of the use of VR equipment by multiple users

Cybersickness

- Cybersickness is a variant of common motion sickness which has negative effects on persons systemic, visual, neural, and psychological status
- Systemic effects are drowsiness, general discomfort, fatigue, disorientation, and stomach awareness
- Interface sickness is nausea due to imperfect simulations (lag times) and eyestrain (flickering, constant refocusing)
- Neural effects from electromagnetic field of CRT HMDs
- Psychological effect include VR system anxieties

Tissue Modeling

- Surgery simulation using fast finite elements
- Real time volumetric deformable models for surgery simulation
- Volumetric deformable models for simulation of laparoscopic surgery
- Real time deformations for surgery

Surgery Simulation Using Fast Finite Elements

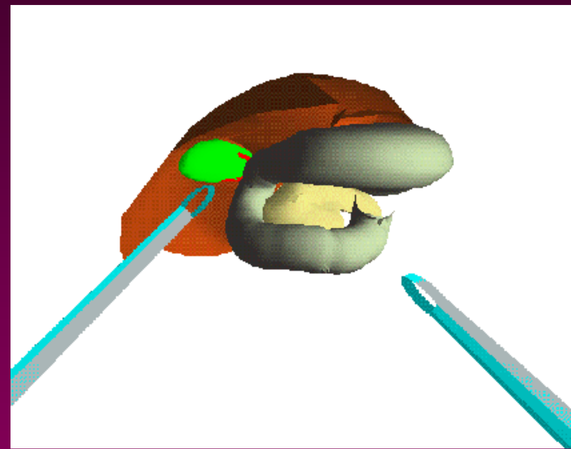
- Bro-Nielsen, TU Denmark
- Fast finite elements (FFE) enable high-speed volumetric model simulation of elastic tissue behavior
- Surface modeling is less optimal then volume modeling for surgical simulations because:
  - with surface modeling there is nothing below the surface
  - simulation of surgical cuts is difficult
- The most important requirement is computation speed
- Condensation is used to lower the order of the linear matrix system that solves the finite element problem
- Visible Human data used to simulate pushing on a leg

Real-Time Volumetric Deformable Models

- S. Cotine et al., INRIA, France
- For simulation of minimally invasive surgery only force-feedback is required
- A volumetric mesh with non-homogeneous elasticity is used for the finite element modeling of an organ
- The simulation works as follows:
  - the surgeon touches the organ with a virtual tool (a force-feedback device)
  - the organ deforms in real-time
  - a non-linear reaction force is computed and sent to a force-feedback device

Georgia Tech

- Georgia Tech's Graphics, Visualization & Usability (GVU) Center
- Research in interactive deformation for surgery simulation
- Developed deformable models based on active surfaces
- methods are applied to the problem of endoscopic gall bladder surgery simulation



Conclusion

- Virtual reality in medicine is a subject of active research
- Active research is in the area of:
  - human-computer interfaces such as force-feedback and tactile interfaces which are important for medical use
  - tissue modeling techniques for simulation of organs
  - display techniques
- We can expect a new generation of diagnostic medical imaging techniques that utilize virtual reality concepts for effective visualization of human anatomy
- This technology will be a building block for new telemedicine applications