Robotic Surgery

ABSTRACT

Just as computers revolutionized the latter half of the 20th century, the field of robotics has the potential to equally alter how we live in the 21st century. Robotics is being introduced to medicine because it allows for unprecedented control and precision of surgical instruments in minimally invasive procedures. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating heart surgery. Three surgical robot systems developed till now are the *Da Vinci Surgical System, ZEUS Robotic Surgical System & AESOP Robotic System*.

1. Introduction

Just as computers revolutionized the latter half of the 20th century, the field of robotics has the potential to equally alter how we live in the 21st century. We've already seen how robots have changed the manufacturing of cars and other consumer goods by streamlining and speeding up the assembly line. We even have robotic lawn mowers and robotic pets. And robots have enabled us to see places that humans are not yet able to visit, such as other planets and the depths of the ocean. In the coming decades, we will see robots that have artificial intelligence, coming to resemble the humans that create them. They will eventually become self-aware and conscious, and be able to do anything that a human can. When we talk about robots doing the tasks of humans, we often talk about the future, but the future of **robotic surgery** is already here.

2. History

In 1985 a robot, the PUMA 560 was used to place a needle for a brain biopsy using CT guidance. In 1988, the PROBOT, developed at Imperial College London, was used to perform prostatic surgery. The ROBODOC from Integrated Surgical Systems was introduced in 1992 to mill out precise fittings in the femur for hip replacement. Further development of robotic systems was carried out by Intuitive Surgical with the introduction of the da Vinci Surgical System and Computer Motion with the *AESOP* and the ZEUS robotic surgical system.

The da Vinci Surgical System comprises three components: a surgeon console, a patient-side robotic cart with 4 arms manipulated by the surgeon (one to control the camera and three to manipulate instruments), and a high-definition 3D vision system. Articulating surgical instruments are mounted on the robotic arms which are introduced into the body through cannulas. The surgeon hand movements are scaled and filtered to eliminate hand tremor then translated into micro-movements of the proprietary instruments. The camera used in the system provides a true stereoscopic picture transmitted to a surgeon's console. The da Vinci System is FDA cleared for a variety of surgical procedures including surgery for prostate cancer, hysterectomy and mitral valve repair, and is used in more than 800 hospitals in the Americas and Europe. The da Vinci System was used in 48,000 procedures in 2006 and sells for about $1.2 million

- In 1997 a reconnection of the fallopian tubes operation was performed successfully in Cleveland using ZEUS.
- In May 1998, Dr. Friedrich-Wilhelm Mohr using the *Da Vinci surgical robot* performed the first robotically assisted heart bypass at the Leipzig Heart Centre in Germany.

- In October 1999 the world's first surgical robotics *beating heart* coronary artery bypass graft (CABG) was performed in Canada using the ZEUS surgical robot.
- In 2001 , Prof. Marescaux used the *Zeus* robot to perform a cholecystectomy on a pig in Strasbourg, France while in New York.
- The first unmanned robotic surgery took place in May 2006 in Italy.

3. First Generation Robotic Surgical Systems

The first generation of surgical robots is already being installed in a number of operating rooms around the world. These aren't true autonomous robots that can perform surgical tasks on their own, but they are lending a mechanical helping hand to surgeons. These machines still require a human surgeon to operate them and input instructions. Remote control and voice activation are the methods by which these surgical robots are controlled. Robotics is being introduced to medicine because they allow for unprecedented control and precision of surgical instruments in minimally invasive procedures. So far, these machines have been used to position an endoscope, perform gallbladder surgery and correct gastroesophogeal reflux and heartburn. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery. According to one manufacturer, robotic devices could be used in more than 3.5 million medical procedures per year in the United States alone. Here are three surgical robots that have been recently developed: **Da Vinci Surgical System, ZEUS Robotic Surgical System & AESOP Robotic System.**

3.1 Da Vinci Surgical Systems

On July 11, 2000, the U.S. Food and Drug Administration (FDA) approved the **Da Vinci Surgical System**, making it the first robotic system allowed to be used in American operating rooms. Developed by Intuitive Surgical, Da Vinci uses technology that allows the human surgeon to get closer to the surgical site

than human vision will allow,
and work at a smaller scale than conventional surgery permits.

Da Vinci surgical system's operating room.

The $1 million Da Vinci system consists of two primary components:

- A viewing and control console
- A surgical arm unit

In using Da Vinci for gallbladder surgery, three incisions -- no larger than the diameter of a pencil -- are made in the patient's abdomen, which allows for three stainless-steel rods to be inserted. The rods are held in place by three robotic arms. One of the rods is equipped with a camera, while the other two are fitted with surgical instruments that are able to dissect and suture the tissue of the gallbladder. Unlike in conventional surgery, these instruments are not directly touched by the doctor's hands.

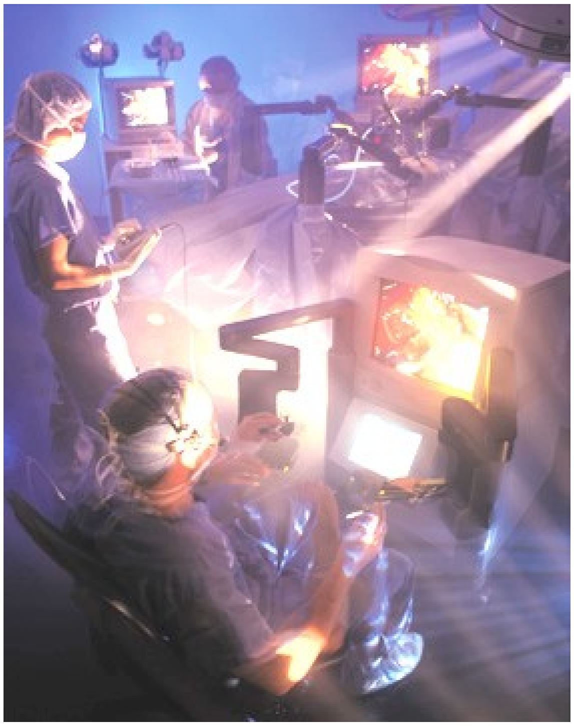
Instruments used in Da Vinci surgical.

Sitting at the control console, a few feet from the operating table, the surgeon looks into a viewfinder to examine the 3- D images being sent by the camera inside the patient. The images show the surgical site and the two surgical instruments mounted on the tips of two of the rods. The surgeon to manipulate the surgical instruments uses joystick-like controls, located just underneath the screen. Each time one of the joysticks is moved, a computer sends an electronic signal to one of the instruments, which moves in sync with the movements of the surgeon's hands.

Surgeon's view when using the Da Vinci surgical system

3.2 ZEUS Robotic System

Another robotic system that is close to being cleared by the FDA is the **ZEUS System**, made by Computer Motion, which is already available in Europe. However, both the Da Vinci and ZEUS systems must receive governmental approval for each procedure that a surgeon plans to use it for. The $750,000 ZEUS has a similar setup to that of the Da Vinci. It has a computer workstation, a video display, and hand controls that are used to move the table-mounted surgical instruments. While the ZEUS system has not yet been cleared for American use beyond clinical trials, German doctors have already used the system to perform coronary bypass surgery. The ZEUS system employs the assistance of the Automated Endoscopic System for Optimal Positioning (**AESOP**) Robotic System. Released by Computer Motion in 1994, AESOP was the first robot to be cleared by the FDA for assisting surgery in the operating room. AESOP is much simpler than the Da Vinci and ZEUS systems. It's basically just one mechanical arm, used by the physician to position the endoscope -- a surgical camera inserted into the patient. Foot pedals or voice-activated software allow the physician to position the camera, leaving his or her hands free to continue operating on the patient.



Doctors seated in the ZEUS Robotic Surgical System can perform minimally invasive surgeries without suffering from fatigue or stress during lengthy operations.

3.3 AESOP (Automated Endoscopic System for Optimal Positioning).

NASA hopes to make use of the technology powering the robotic arm of AESOP to service satellites and inspect payloads on the Space Shuttle in the future. The hope is to use robotics on space repair missions requiring exact and precise movements that exceed human dexterity.

Nearly a million endoscopic surgeries are performed annually by inserting a slender camera into a small incision in the patient to access the part of the body targeted for the operation. The surgeon uses the camera to monitor the operation, which requires long, narrow instruments. This endoscopic approach reduces the healing and recovery time needed by the patient and lowers healthcare costs.

Now, with Computer Motion's AESOP, surgeons can control the motion of the camera, which is attached to a robotic arm. AESOP eliminates the need for surgical staff to hold the camera in place. The robotic arm also allows for a steadier view of the surgery and more precise and consistent movements of the camera.

The AESOP arm uses Computer Motion's voice recognition software, which is pre-recorded onto a voice card and inserted into the controller. Computer Motion's NASA-funded research determined that voice controlled commands are preferred in the operating room as opposed to alternatives such as eye-tracking and head-tracking, which control motion in response to movements of the surgeon's head.

A second generation of this technology, called the ZEUS Robotic Surgical System, has the potential to make endoscopic procedures even more accessible. Traditional endoscopic methods require a long learning curve and a greater dexterity than some possess. Also, suturing for microsurgical procedures such as endoscopic coronary artery bypass graft often exceeds typical human dexterity limits.

However, through the use of a master-slave robotic system, surgeon motions are scaled down, allowing the doctor to make more natural movements. By manipulating additional robotic arms, the surgeon can move the instruments with the precision the procedure requires. Incisions can be made smaller than the diameter of a pencil as compared to the 12- to 15-inch incision and cracked ribs traditional open-heart surgery requires.

One final benefit of the ZEUS
system is that it allows the surgeon to perform the operation seated in an ergonomic position, eliminating the problems of fatigue and frustration resulting from leaning over the patient in an awkward posture for hours.

AESOP, a voice-controlled robotic endoscopic positioning system provides an absolutely steady picture during minimally invasive surgeries.

Last summer, the first completely endoscopic coronary artery bypass graft was performed using the ZEUS system and has now been put in use at 19 sites. Computer Motion hopes to use AESOP and ZEUS as the cornerstone technologies for tomorrow's Intelligent Operating Room.

4. Applications

a. **Cardiac surgery**

Endoscopic coronary artery bypass (TECAB) surgery and mitral valve replacement have been performed. Totally closed chest, endoscopic mitral valve surgeries are being performed now with the robot. Irfan mulic was the first person to have this done to him

b. **Gastrointestinal surgery**

Multiple types of procedures have been performed with either the *Zeus* or *da Vinci robot* systems, including bar iatric surgery.

c. **Gynecology**

Robotic surgery in gynecology is one of the fastest growing fields of robotic surgery. This includes the use of the da Vinci surgical system in benign gynecology and gynecologic oncology. Robotic surgery can be used to treat fibroids, abnormal periods, endometriosis, ovarian tumors, and pelvic prolapsed and female cancers. Using the robotic system, gynecologists can perform hysterectomies, myomectomies, and lymph node biopsies. The need for large abdominal incisions is virtually eliminated.

d. **Neurosurgery**

Several systems for stereo tactic intervention are currently on the market. MD Robotics' Neuro Arm is the world's first MRI-compatible surgical robot.

e. **Orthopedics**

The ROBODOC system was released in 1992 by the Integrated Surgical Systems, Inc.

f. **Pediatrics**

Surgical robotics has been used in many types of pediatric surgical procedures including: tracheoesophageal fistula repair, cholecystectomy, nissen fundoplication, morgagni hernia repair, Kasai portoenterostomy, congenital diaphragmatic hernia repair, and others. On January 17, 2002, surgeons at Children's Hospital of Michigan in Detroit performed the nation's first advanced computer-assisted robot-enhanced surgical procedure at a children's hospital.

Radio surgery

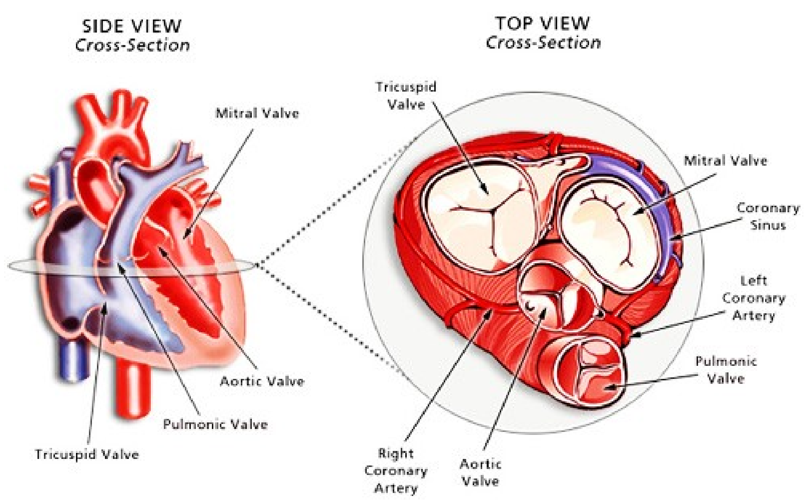
The Cyber Knife Robotic Radio surgery System uses image-guidance and computer controlled robotics to treat tumors throughout the body by delivering multiple beams of high-energy radiation to the tumor from virtually any direction.

Urology

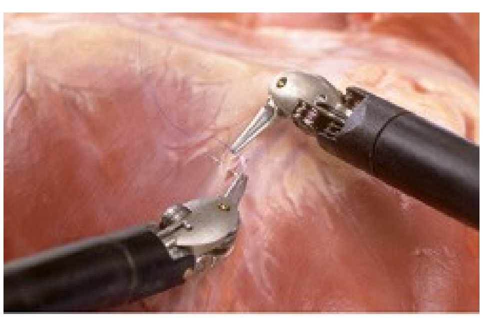
The da Vinci robot is commonly used to remove the prostate gland for cancer, repair obstructed kidneys, repair bladder abnormalities and remove diseased kidneys.

4.1 Robotic Cardiac Surgery

When Vaughn. A. Starnes, M. D., professor and chairman of the Department of Cardiothoracic Surgery at the Keck School of Medicine of the University of Southern California, took a seat at the instrument control console of the da Vinci Surgical System on April 27, 2001, he prepared to make history yet again--becoming the first cardiothoracic surgeon in Southern California to perform heart surgery using a robot.



Cross-section showing valves of the heart.

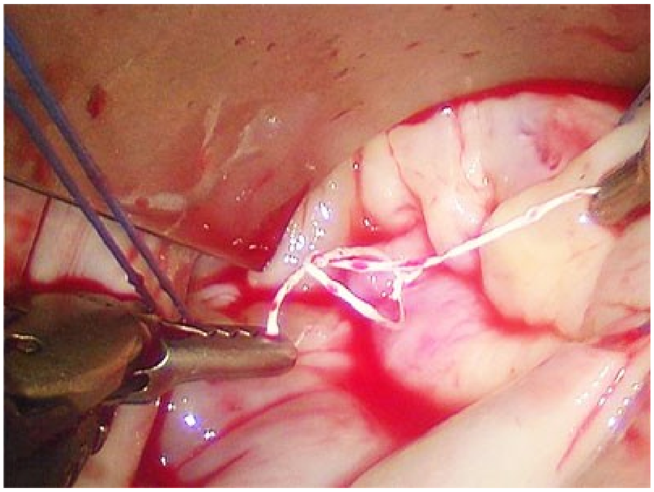


And as Dr. Starnes methodically repaired Lottie Henderson's leaky mitral valve, USC Cardiothoracic Surgeons entered a new era of advanced heart surgery.

During this ground-breaking procedure, Dr. Starnes sat at a console about 8 feet away from the patient, while another surgeon positioned the three-armed, 1,000-pound robot beside her. Dr. Starnes grasped and moved highly sensitive instruments at the console while viewing Henderson's heart – greatly magnified – on a screen. The robot precisely matched Dr. Starnes' natural hand and wrist movements, translating them to the tiny instruments placed inside the patient through small puncture incisions.

The surgeons repaired Lottie's leaky mitral valve. This valve, which helps pump blood through the heart, separates the heart's upper chamber from its lower chamber. A weakened valve due to leakage can result in blood backing up into the lungs, causing the ventricle to pump more blood and producing symptoms of shortness of breath and tiredness.

The robotic procedure required three small incisions between the ribs, two for the insertion of interchangeable instruments and another for a thin, cylindrical video camera, called an endoscope. Dr. Starnes shaped and sutured tissue into place, shortening a chord (a sort of "heart string" that supports the heart valve). He also sewed a ring into place to brace the valve.



Mitral valve repair using da Vinci Surgical System

Mitral valve repairs are among those requiring the most skill from a surgeon. This is a procedure not many people across the country do – even without a robot. The robot is able to perfectly mimic the surgeon's hand, all in a small area.

The robot can be so delicate that
you can carefully place sutures the size of a human hair.

Robotic surgery is the use of robots in performing surgery. Three major advances aided by surgical robots have been remote surgery, minimally invasive surgery and unmanned surgery. Major potential advantages of robotic surgery are precision and miniaturization. Further advantages are articulation beyond normal manipulation and three-dimensional magnification.

4.2 Miniature robotics

As scientists seek to improve the versatility and utility of robotics in surgery, some are attempting to miniaturize the robots. For example, the University of Nebraska Medical Center has led a multi-campus effort to provide collaborative research on mini-robotics among surgeons, engineers and computer scientists. [6] Scientists at Hebrew University have also developed a miniature robot to navigate through the bloodstream.

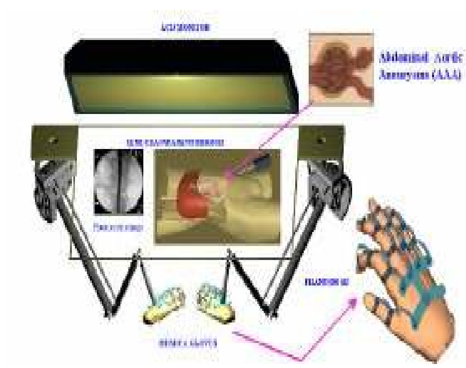
4.3 Robotic Telesurgery

In today's operating rooms, you'll find two or three surgeons, an anesthesiologist and several nurses, all needed for even the simplest of surgeries. Most surgeries require nearly a dozen people in the room. As with all automation, surgical robots will eventually eliminate the need for some of those personnel. Taking a glimpse into the future, surgery may require only one surgeon, an anesthesiologist and one or two nurses. In this nearly empty operating room, the doctor will sit at a computer console, either in or outside the operating room, using the surgical robot to accomplish what it once took a crowd of people to perform. The use of a computer console to perform operations from a distance opens up the idea of **tele-surgery**, which would involve a doctor performing delicate surgery miles away from the patient. If the doctor doesn't have to stand over the patient to perform the surgery, and can remotely control the robotic arms at a computer station a few feet from the patient, the next step would be performing surgery from locations that are even farther away. If it were possible to use the computer console to move the robotic arms in **real-time**, then it would be possible for a doctor in California to operate on a patient in New York. A major obstacle in tele-surgery has been the time delay between the doctors moving his or her hands to the robotic arms responding to those movements. Currently, the doctor must be in the room with the patient for robotic systems to react instantly to the doctor's hand movements.

4.3.1 Robotic Telesurgery using Hap tic Mechanism called MEMICA

The key to the development of the hap tic system, MEMICA, is the use of liquids that change viscosity when subjected to electric field. Such liquids that are called Electro-Rheological Fluid (ERF) were known to exit for over fifty years. ERF exhibit a rapid, reversible and tunable transition from a fluid state to a solid-like state upon the application of an external electric field. Some of the advantages of ERFs are their high yield stress, low current density, and fast response (less than 1 millisecond). ERFs can apply very high electrically controlled resistive forces while their size (weight and geometric parameters) can be very small. Their long life and ability to function in a wide temperature range (as much as – 40C to +200C) allows for the possibility of their use in distant and extreme environments. ERFs are also not abrasive, and they are non-toxic, and non-polluting (meet health and safety regulations). ERFs can be combined with other actuator types such as electromagnetic, pneumatic or electrochemical actuators so that novel, hybrid actuators are produced with high power density and low energy requirements. The electrically controlled rheological properties of ERFs can be beneficial to a wide range of technologies requiring damping or resistive force generation. Examples of such applications are active vibration suppression and motion control.

Several commercial applications have been explored, mostly in the automotive industry for ERF-based engine mounts, shock absorbers, clutches and seat dampers. Other applications include variable resistance exercise equipment, earthquake-resistant tall structures and positioning devices. While ERFs have fascinated scientists, engineers and inventors for nearly fifty years, and have given inspiration for developing ingenious machines and mechanisms, their applications in real life problems and the commercialization of ERF-based devices have been very limited. There are several reasons for this. Due to the complexity and non-linearities ties of their behavior, their closed-loop control is a difficult problem to solve. In addition, the need for high voltage to control ERF-based devices creates safety concerns for human operators, especially when ERFs are used in devices that will be in contact with humans. Their relatively high cost and the lack of a large variety of commercially available ERFs with different properties to satisfy various design specifications made the commercialization of ERF-based devices unprofitable. However, research on ERFs continues intensively and new ERF-based devices are being proposed. This gives rise to new technologies that can benefit from ERFs.



Performing Virtual Reality Medical Tasks via the Electro-Rheological Fluid Based MEMICA Hap tic Interface.

One such new technological area, which will be described in detail here, is virtual reality and telepresence, enhanced with hap tic (i.e. tactile and force) feedback systems and for use in, for example, medical applications. In this paper, we describe a novel ERF-based hap tic system called MEMICA **(remote**

Mechanical Mirroring using Controlled stiffness and Actuators). MEMICA is intended to provide human operators an intuitive and interactive feeling of the stiffness and forces in remote or virtual sites in support of space, medical, underwater, virtual reality, military and field robots performing dexterous manipulation operations. MEMICA is currently being sought for use to perform virtual Telesurgery as shown in and it consists of miniature **Electrically Controlled Stiffness (ECS) elements and Electrically Controlled Force and Stiffness (ECFS) actuators** that mirror the stiffness and forces at remote/virtual sites.

4.3.2 Hap tic Interfaces and Electrorheological Fluids

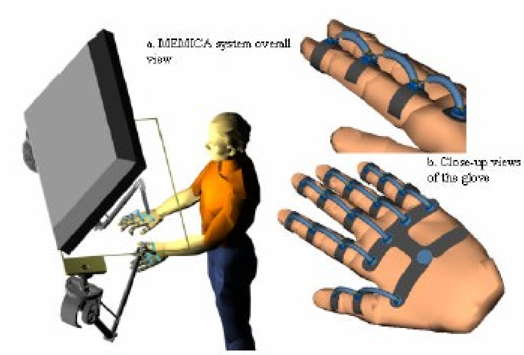
Hap tic (tactile and force) feedback systems are the engineering answer to the need for interacting with remote and virtual worlds and currently it is a less developed modality of interacting with remote and virtual worlds compared with visual and auditory feedback. Thus, realism especially suffers when remote and virtual tasks involve dexterous manipulation or interaction in visually occluded scenes. A very good description of the current state-of-the-art in hap tic and force feedback systems can be found in. Tactile sensing is created by skin excitation that is usually produced by devices known as “tactile displays”. These skin excitations generate the sensation of contact. Force-sensitive resistors, miniature pressure transducers, ultrasonic force sensors, piezoelectric sensors, vibrotactile arrays, thermal displays and electro-rheological devices are some of the innovative technologies that have been used to generate the sensation of touch. While tactile feedback was conveyed by the mechanical smoothness and slippage of a remote object, it could not produce rigidity of motion. Thus, tactile feedback alone cannot convey the mechanical compliance, weight or inertia of the virtual object being manipulated. Force feedback devices are designed to apply forces or moments at specific points on the body of a human operator. The applied force or moment is equal or proportional to a force or moment generated in a remote or virtual environment. Thus, the human operator physically interacts with a computer system that emulates a virtual or remote environment. Force feedback devices include portable and non portable interfaces. Force feedback joysticks, mice and small robotic arms such as the Phantom are non-portable devices that allow users to feel the geometry, hardness and/or weight of virtual objects. Portable systems are force feedback devices that are *grounded* to the human body. They are distinguished as *arm exoskeletons* if they apply forces at the human arm and as *hand-masters* if they apply forces at the human's wrist and/ or palm. Portable hand masters are hap tic interfaces that apply forces to the human hand while they are attached at the human operator forearm. In most cases, these systems look like gloves where the actuators are placed at the human forearm and forces are transmitted to the fingers using cables, tendons and pulleys. The Cyber Grasp is an example of such a system, which is a lightweight, force reflecting exoskeleton glove that fits over a Cyber Glove and adds resistive force feedback to each finger via a network of tendons routed around an exoskeleton. The actuators are high quality DC motors located in a small enclosure on the desktop. The remote reaction forces can be emulated very well; however, it is difficult to reproduce the feeling of "remote stiffness". To date, there are no effective commercial unencumbering hap tic feedback devices for the human hand. Current "hand master" hap tic systems, while they are able to reproduce the feeling of rigid objects, present great difficulties in emulating the feeling of remote / virtual stiffness. In addition, they tend to be heavy and cumbersome with low bandwidth, and they usually only allow limited operator workspace.

The Cyber Grasp glove with force feedback.

During the last ten years, some researchers proposed the use of ERFs in an effort to improve the performance of hap tic interfaces. There are many properties of ERFs that can greatly improve the design of hap tic devices. Their high yield stress, combined with their small sizes can result in miniature hap tic devices that can easily fit inside the human palm without creating any obstructions to human motion. ERFs do not require any transmission elements to produce high forces, so direct drive systems can be produced with less weight and inertia. The possibility of controlling the fluids' rheological properties gives designers of ERF-based hap tic system the possibility of controlling the system compliance; and hence, mirrors accurately remote or virtual compliance. Finally, ERFs respond almost instantly, in milliseconds, which can permit very high bandwidth control important for mirroring fast motions. The only concern that a designer of ERF-based hap tic interfaces may have is the need for high voltages to develop the forces and compliance required. This has two consequences:

A) It increases the complexity of the electronic system needed to develop the high voltage and
B) It raises safety concerns for the human operator. Both issues can be solved easily with modern electronic circuit design techniques.

Nowadays, low power, small size circuits can be used to generate the required high voltage using a very low current on the order of micro-amps. Consequently, the required power becomes extremely low, in the order of mW, posing no hazard for human operators. Kenaley and Cutkosky were the first to propose the use of ERFs for tactile sensing in robotic fingers. Based on that work, several workers proposed the use of ERFs in tactile arrays used to interact with virtual Environments and also as assistive devices for the blind to read the Braille system. The first to propose this application of ERFs was Monk man. Continuing this work, Taylor and his group at the University Of Hull, UK, developed and tested experimentally a 5x5 ERF tactile array. Professor Furusho and his group at Osaka University in Japan developed an ERF-based planar force-feedback manipulator system that interacts with a virtual environment. Low-inertia motors equipped with an ER clutch actuate this system. An ERF-based force-feedback joystick has been developed in Fraunhofer-Institute in Germany. The joystick consists of a ball and socket joint where ERF has been placed in the space between the ball and the socket. The operator feels a resistive force to his/her motion resulting from the controlled viscosity of the ERF. Finally, MEMICA that is described in this paper, which is being developed by researchers at Rutgers University and JPL, employs ERF-based force-feedback gloves.

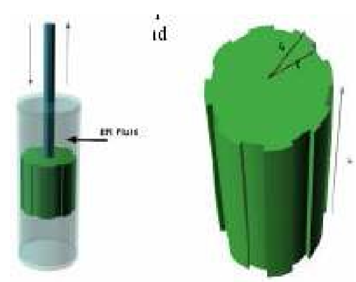


3D View from the MEMICA System and Close-up View of the gloves with the ECFS actuators.

4.3.3 MEMICA Hap tic Glove

The key aspects of MEMICA are miniature ECS elements and ECFS actuators that mirror the forces and stiffness at remote/ virtual sites. The ECS elements and ECFS actuators which make use of ERFs to achieve this feeling of remote / virtual forces are placed at selected locations on an instrumented glove to mirror the forces of resistance at the corresponding locations in the robot hand.

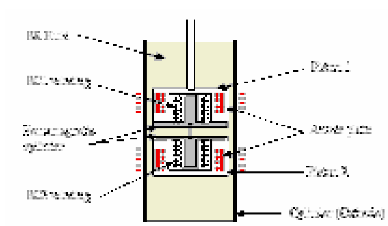
A) Electrically Controlled Stiffness (ECS) Element: The stiffness that is felt via the ECS element is modified electrically by controlling the flow of ERF through slots on the side of a piston. The ECS element consists of a piston that is designed to move inside a sealed cylinder filled with ERF. Electrodes facing the flowing ERF while inside the channel control the flow rate electrically. To control the "stiffness" of the ECS element, a voltage is applied between electrodes facing the slot, affecting the ability of the liquid to flow. Thus, the slot serves as a liquid valve, since the increased viscosity decreases the flow rate of the ERF and varies the stiffness felt. To increase the stiffness bandwidth from free flow to maximum viscosity, multiple slots are made along the piston surface. To wire such a piston to a power source, the piston and its shaft are made hollow and electric wires are connected to electrode plates mounted on the side of the slots. The inside surface of the ECS cylinder surrounding the piston is made of a metallic surface and serves as the ground and opposite polarity. A sleeve covers the piston shaft to protect it from dust, jamming or obstruction. When a voltage is applied, potential is developed through the ERF along the piston channels, altering its viscosity.



ECS Element and Its Piston.

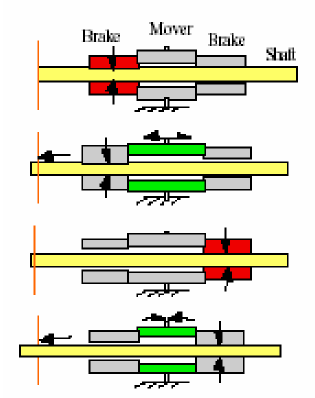
B) Electrically Controlled Force and Stiffness (ECFS) Actuator: To produce complete emulation of a mechanical "tele-feeling" system, it is essential to use actuators in addition to the ECS elements in order to simulate remote reaction forces. Such a hap tic mechanism needs to provide both active and resistive actuation. The active actuator can mirror the forces at the virtual/remote site by pulling the finger or other limbs backward. This actuator operates as an *inchworm* motor and consists of active and passive elements, i.e., two brakes and an expander, respectively. One brake locks the motor position onto a shaft and the expander advances (stretches) the motor forward. While the motor is stretched forward, the other brake clamps down on the shaft and the

first brake is released. The
process is repeated as necessary, inching forward (or backward) as an inchworm does in nature. Using the controllability of the resistive aspect of the ERF, a brake can be formed to support the proposed inchworm. A schematic description of the ECFS actuator. The actuator consists of two pistons (brake elements) and two electromagnetic cylinders (pusher element). Similar to ECS, each piston has several small channels with a fixed electrode plate. When an electric field is induced between the piston anode and cylinder cathode, the viscosity of the ERF increases and the flow rate of the fluid though the piston channel decreases securing the piston to the cylinder wall. Each of the electromagnetic cylinders consists of a coil and a ferromagnetic core integrated within the piston. When a current impulse is passed through the winding, an electromagnetic field is induced and depending on the current direction, the cylinder moves forward or backward.



ECFS actuator configuration.

At each cycle, the pistons move forward or backward with very small displacement (<1.5mm). The duration of each cycle is close to a millisecond, corresponding to the response time of the ERF. The ECFS actuator can then reach a speed higher than 15-cm/s with a piston displacement equal to 0.5-mm at 3-ms cycle duration. The electromagnetic cylinder is designed to produce the same force as the resistive force of the piston inside the ERF, which is about 15N.



Concept of Inchworm motor

C) MEMICA Hap tic Glove and System:A hap tic exoskeleton integrates the ECS elements and ECFS actuators at various joints. As shown in Figure 5, the actuators are placed on the back of the fingers, out of the way of grasping motions. The natural motion of the hand is then unrestricted. Also, this configuration is capable of applying an independent force (uncoupled) on each phalange to maximize the level of stiffness/force feedback that is "felt" by the operator. Different mounting mechanisms are currently being evaluated where the most ergonomic seems to be the use of an arched actuator providing a better fitting with the finger motion and geometry. Since the ERF viscosity is higher than air, there is no need for tight tolerance for the ECFS piston and its cylinder. The second proposed solution uses curved sliding rail, which is also suitable for a finger motion. The third solution uses a flexible tendon connected directly to the piston inside the cylinder where the tendon length can be adjustable to the user phalange length.

5.

Need for Robotic Surgery

A robotic surgery system has multiple advantages for the doctor as well as the patient. It provides the doctor:

A) Enhanced 3-D Visualization: Provides the surgeon with a true 3- dimensional view of the operating field. This direct and natural hand-eye instrument alignment is similar to open surgery with "all-around" vision and the ability to zoom-in and zoom-out.

B) Improved Dexterity: Provides the surgeon with instinctive operative controls that make complex MIS procedures feel more like open surgery than laparoscopic surgery.

C) Greater Surgical Precision: Permits the surgeon to move instruments with such accuracy that the current definition of surgical precision is exceeded.

D) Improved Access: Surgeons perform complex surgical maneuvers through 1-cm ports, eliminating the need for large traumatic incisions.

E) Increased Range of Motion: Instruments restore full range of motion and ability to rotate instruments more than 360 degrees through tiny incisions.

F) Reproducibility: Enhances the surgeon's ability to repetitively perform technically precise maneuvers such as endoscopic suturing and dissection.

Robotic surgery has the following advantages for the patient:

A) Reduced trauma to the body

B) Less anesthesia

C) Less blood loss and need for transfusions

D) Less post-operative pain and discomfort

E) Less risk of infection

F) Shorter hospital stay

G) Faster recovery and return to normal daily activities

H) Less scarring and improved cosmetics

5.1 Benefits of Robotic Surgery

Dr. Starnes has focused his clinical and research efforts on minimally invasive heart surgery, specifically "off-pump" coronary artery bypass grafting and mitral valve repair. He is very involved in the robotic surgery research efforts.

Indeed, traditional mitral valve surgery involves a long incision, and surgeons must split the breast bone to reach the heart. Even using advanced techniques, the incision can be four inches long. But through the small punctures and tiny instruments involved in minimally invasive robotic surgery, patients experience shorter incisions.

Dr. Starnes explains that the robot can accomplish what the human surgeon cannot because of its ability to mimic the human hand within a small, contained space. The EndoWrist™ Instruments transform the surgeons’ wrists, hand and fingers into tiny instruments.

During the procedure, while the console surgeon operates the sophisticated robot from a distance, the bedside surgeon is responsible for placement of the correct surgical ports and directing the robot into the patient. And like other heart surgery, nurses and anesthesiologists play key roles during the procedure.

In the future, the USC Department of Cardiothoracic Surgery hopes to apply this technology to other types of heart surgery, including off-pump coronary artery surgery as well as treating intracardiac lesions, including atrial septal defects and ventricle septal defects.

6. Future of Robotic Surgery

Dr. Starnes notes that the USC Department of Cardiothoracic Surgery is developing a Robotic Surgery Institute and Laboratory that will encompass all surgical specialties that could benefit from robotic surgery such as general surgery, urology and orthopedics. With cardiothoracic surgery leading the way, the Robotic Surgery Institute promises to create new treatment alternatives for patients.

This project is in addition to the new Cardiothoracic Institute being built adjacent to USC University Hospital and scheduled for completion by 2007. This multi-story building will bring the full range of heart experts together, so that patients can visit world-class cardiologists and cardiothoracic surgeons all in one setting. Sophisticated cardiology diagnostic services will share the same building with cutting-edge researchers and scientists, allowing physicians and researchers to directly interact -- leading to breakthroughs that truly translate from the laboratory into the clinical setting.

"Robotic surgery is going to revolutionize cardiothoracic procedures," says Dr. Starnes, "and it is exciting that USC has the leading program in Los Angeles for this technology. Robotic surgery truly represents the next advance in heart surgery."

7. Conclusion

With the introduction of robots in surgery during the early 80s, numerous promises came along with their use, many of which did not achieve clinical significance? The advent of minimally invasive surgery and the resulting boundaries for the surgeon due to the length of the instruments, reduction in degrees of freedom, 2D image, and lack of hap tics, called on robots to improve these limitations and they once again appeared to show potential. Investments in the field led to the development of three robots (1): Aesop, Zeus, and DaVinci. Neither of those was granted the designation of "robot" by the FDA as none were capable of automated pre-programmed surgical tasks, the official definition of a robot. However, all have led to some clinical breakthroughs. The Aesop was found to be a useful assistant during long laparoscopic surgeries; the Zeus with its bed-mounted feature and ability to use 5 mm instruments, and its telesurgical capability, was used efficiently in pediatric surgery and remote telepresence surgery (2, 3); and the DaVinci, with its 6 degrees of freedom, has improved surgeon's precision to carry out delicate tasks in confined spaces (1). In fact, in recent years, robotic prostatectomy has become the most popular approach to this surgery in the United States and has boosted the prevalence and sale of robotics across the USA. Whilst some may argue that robotic cardiac surgery or tele robotic telepresence surgery may have been a more impressive and groundbreaking demonstration of the capabilities of robotics, it is undeniable that robotic prostatectomy has been the "killer ap" which broke the ice and introduced robotics into the mainstream use. The establishment of Minimally Invasive Robotic Association (MIRA), an international body dedicated to the promotion of robotics in surgery, is a sign of this breakthrough.

Today, with the broader availability of robots, more and more surgeons are evaluating their clinical significance in a wide range of surgeries. Furthermore, uncharted areas of image-guided surgery (4), preplanning and automation are once again of interest to researchers and to industry. Telepresence surgery also continues to garner significant interest and there are ongoing investments for research in this field, particularly by the US military and NASA, the two organizations which should be credited with the early investments that got the ball rolling and the current edition of robots on the market.

WeBSurg is dedicated to presenting the latest techniques and technology to help surgeons and intervention lists keep abreast of these developments and provide an educational platform for their needs. We presented a number of robotic breakthroughs in the past. However with increasing clinical and research applications we have decided to dedicate a new section to Robotic Surgery on WeBSurg. The section, which will be presented in collaboration with MIRA, will include: articles by pioneers in the field, video demonstration of robotic surgery by experts, news of recent developments, new techniques, upcoming robotic conferences and courses.

A hap tic mechanism was described that can allow operators to sense the interaction of stiffness and forces exerted on a robotic manipulator. A key to the new hap tic interface is the so-called electrically controlled stiffness (ECS) element, which was demonstrated in a scaled size experimental unit proving the feasibility of the mechanism. A conceptual novel ERF based hap tic system called MEMICA that is based on such ECS elements was described. MEMICA is intended for operations in support of space, medical, underwater, virtual reality, military and field robots performing dexterous manipulations. For medical applications, virtual procedures can be developed as simulators to allow training doctors, an exoskeleton system can be developed to augment the mobility of handicapped or ill persons, and remote surgery can be enabled.