Robotics in Surgery

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Certificate

Certified that this is a bonafide record of the seminar entitled

"ROBOTICS IN SURGERY"

presented by the following student

"KANIKA SINGH"

of the VIIth semester, Computer Science and Engineering in the year 2010 in partial fulfillment of the requirements in the award of Degree of Bachelor of Technology in Computer Science and Engineering of Cochin University of Science and Technology.

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KANIKA SINGH

ABSTRACT

The field of surgery is entering a time of great change, spurred on by remarkable recent advances in surgical and computer technology. Only recently have robotic systems made their way into the operating room as dexterity-enhancing surgical assistants and surgical planners, in answer to surgeons' demands for ways to overcome the surgical limitations of minimally invasive laparoscopic surgery.

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, but they are lending a mechanical helping hand to surgeons. 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. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery.

Robots in the field of surgery have dramatically changed the procedures for the better. The most significant advantage to Robotic Surgery to the patient is the decrease in pain and scaring. The smallness of the incisions also causes many other advantages that make Robotic Surgery worth the risk. Besides the obvious rewards to the patient, Robotic Surgery is also very advantageous to the surgeon and hospital.

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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 may see robots that have artificial intelligence. Some, like Honda's ASIMO (Fig 1.1) robot, will resemble the human form. They may 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 robotic surgery is already a reality. Doctors around the world are using sophisticated robots to perform surgical procedures on patients. While robotic surgery systems are still relatively uncommon, several hospitals around the world have bought robotic surgical systems. These systems have the potential to improve the safety and effectiveness of surgeries. But the systems also have some drawbacks. It's still a relatively young science and it's very expensive. Some hospitals may be holding back on adopting the technology. 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.


Fig 1.1 Honda ASIMO robot.

1.1 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.

• 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.

Fig 1.2 HelpMate Robotic System
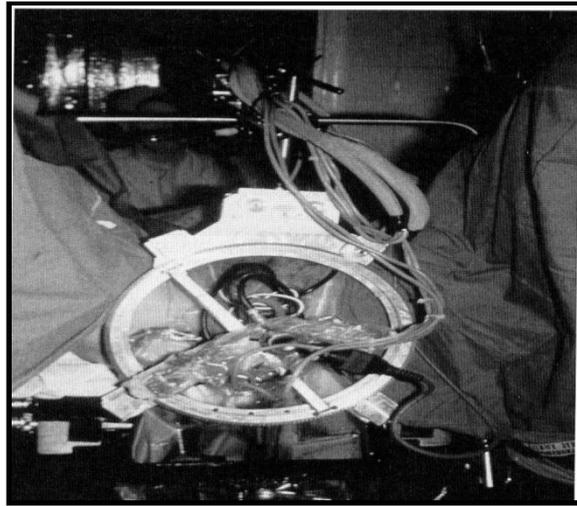
Fig 1.3 Probot System
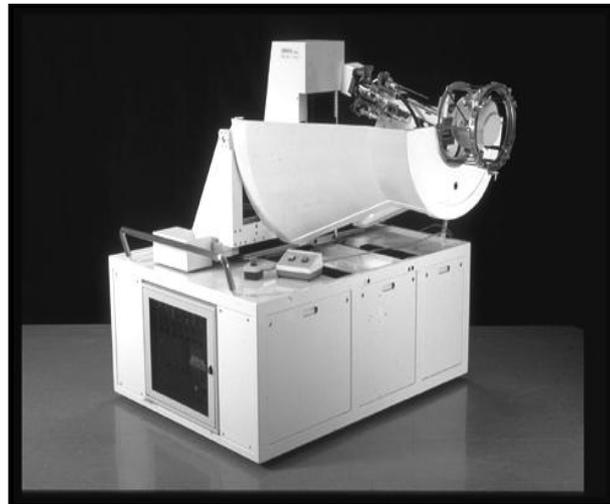
Fig 1.4 Minerva Robotic System

2. ROBOTIC SYSTEM

The first generation of surgical robots are 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 gastro-oesophageal 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 (Fig 2.1)**

• **ZEUS Robotic Surgical System (Fig 2.2)**

• **AESOP Robotic System (Fig 2.3)**

Fig 2.1 Da Vinci System

Fig 2.2 Zeus System

Fig 2.3 Aesop's System

3. **CLASSIFICATION**

Not all surgical robots are equal. There are three different kinds of robotic surgery systems: supervisory-controlled systems, telesurgical systems and shared-control systems. The main difference between each system is how involved a human surgeon must be when performing a surgical procedure. On one end of the spectrum, robots perform surgical techniques without the direct intervention of a surgeon. On the other end, doctors perform surgery with the assistance of a robot, but the doctor is doing most of the work.

There are mainly three telesurgical robotic systems namely:

- ✓ da Vinci Surgical System,
- ✓ ZEUS Robotic Surgical System
- ✓ AESOP Robotic System

3.1 SUPERVISORY-CONTROLLED ROBOTIC SURGERY SYSTEMS

Of the three kinds of robotic surgery, supervisory-controlled systems are the most automated. But that doesn't mean these robots can perform surgery without any human guidance. In fact, surgeons must do extensive prep work with surgery patients before the robot can operate.

Fig 3.1 Demonstration of a supervisory-controlled robotic system.

That's because supervisory-controlled systems follow a specific set of instructions when performing a surgery. The human surgeon must input data into the robot, which then initiates

a series of controlled motions and completes the surgery. There's no room for error -- these robots can't make adjustments in real time if something goes wrong. Surgeons must watch over the robot's actions and be ready to intervene if something doesn't go as planned. The reason surgeons might want to use such a system is that they can be very precise, which in turn can mean reduced trauma for the patient and a shorter recovery period. One common use for these robots is in hip and knee replacement procedures. The robot's job is to drill existing bone so that an implant fits snugly into the new joint. Because no two people have the exact same body structure, it's impossible to have a standard program for the robot to follow. That means surgeons must map the patient's body thoroughly so that the robot moves in the right way. They do this in a three-step process called planning**,** registration and navigation.

In the planning stage, surgeons take images of the patient's body to determine the right surgical approach. Common imaging methods include computer tomography (CT) scans, magnetic resonance imaging (MRI) scans, ultrasonography, fluoroscopy and X-ray scans. For some procedures, surgeons may have to place pins into the bones of the patient to act as markers or navigation points for the computer. Once the surgeon has imaged the patient, he or she must determine the surgical pathway the robot will take. The surgeon must tell the robot what the proper surgical pathway is. The robot can't make these decisions on its own. Once the surgeon programs the robot, it can follow instructions exactly.

The next step is registration. In this phase, the surgeon finds the points on the patient's body that correspond to the images created during the planning phase. The surgeon must match the points exactly in order for the robot to complete the surgery without error.

The final phase is navigation. This involves the actual surgery. The surgeon must first position the robot and the patient so that every movement the robot makes corresponds with the information in its programmed path. Once everyone is ready, the surgeon activates the robot, which carries out its instructions.

3.2 TELESURGICAL SYSTEMS

3.2.1 THE DA VINCI SURGICAL SYSTEM

A product of the company Intuitive Surgical, the da Vinci Surgical System is perhaps the most famous robotic surgery apparatus in the world. It falls under the category of telesurgical devices, meaning a human directs the motions of the robot. In a way, this makes the robot a very expensive high-tech set of tools. On July 11, 2000, the U.S. Food and Drug Administration (FDA) approved the da Vinci Surgical System for laparoscopic procedures,

making it the first robotic system allowed in American operating rooms. The 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.

Fig 3.2.1.1 Types of instruments used by the da Vinci Surgical System

The $1.5 million da Vinci system consists of two primary components:

• A viewing and control console

• A surgical arm unit that includes three or four arms, depending on the model

It has four robotic arms. Three of them are for tools that hold objects, act as a scalpel, scissors, bovie, or unipolar or dipolar electrocautery instruments. The fourth arm is for a camera with two lenses that gives the surgeon full stereoscopic vision from the console. The surgeon is seated at a set of controls and looks through two eye holes at a 3-D image of the procedure, while maneuvering the arms with two foot pedals and two hand controllers. In using da Vinci for surgery, a human surgeon makes three or four incisions (depending on the number of arms the model has) -- no larger than the diameter of a pencil -- in the patient's abdomen, which allows the surgeons to insert three or four stainless-steel rods. The robotic arms hold the rods in place. One of the rods has two endoscopic cameras inside it that provide a stereoscopic image, while the other rods have surgical instruments that are able to dissect and suture the tissue. Unlike in conventional surgery, the doctor does not touch these surgical instruments directly. 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 or three surgical instruments

mounted on the tips of the surgical rods. The surgeon uses joystick-like controls located underneath the screen to manipulate the surgical instruments (Fig 3.2.1.1). Each time the surgeon moves one of the joysticks, a computer sends an electronic signal to one of the instruments, which moves in sync with the movements of the surgeon's hands. Working together, surgeon and robot can perform complete surgical procedures without the need for large incisions. Once the surgery is complete, the surgeons remove the rods from the patient's body and close the incisions.

The da Vinci System is FDA cleared for a variety of surgical procedures. These procedure include:

- Prostate cancer surgery.
- Hysterectomy.
- Mitral valve repair.
- Prostatectomies
- Cardiac valve repair
- Gynecologic surgical procedures
- Abdominal surgical procedures
- Thoracic surgical procedures

Surgeons are beginning to employ the da Vinci System to remove tumors on the liver and pancreas, on account of the delicacy of the procedure, the number of blood vessels that the surgeon must deal with, and the single location of the operation. Procedures that are not localized and require the surgeon to move around to different areas are very inconvenient, considering the time it takes to set up the da Vinci System's ports.

Fig 3.2.1.1 Da Vinci Surgical System

3.2.2 ZEUS ROBOTIC SURGICAL SYSTEM

The ZEUS Surgical System is made up of an ergonomic surgeon control console and three table-mounted robotic arms, which perform surgical tasks and provide visualization during endoscopic surgery. Seated at an ergonomic console with an unobstructed view of the OR, the surgeon controls the right and left arms of ZEUS,

which translate to real-time articulation of the surgical instruments. A third arm incorporates the AESOP® Endoscope Positioner technology, which provides the surgeon with magnified, rock-steady visualization of the internal operative field.

Fig 3.2.2.1 Zeus System

Peerless voice control capabilities allow the surgeon to precisely guide the movements of the endoscope with simple spoken commands, freeing the surgeon's hands to manipulate the robotic surgical instrument handles. ZEUS custom scales the movement of these handles and filters out hand tremor, enabling surgeons with greater capability to perform complex micro-surgical tasks.

The ZEUS Surgical System features the following components:

- Video Console
- Primary Video Monitor up to 23"W x 23"D
- Flat Panel Monitor: with support for an additional flat panel monitor

Fig 3.2.2.2 Components

Surgeon Control Console

- Touch Screen Monitor
- Support Arms and Surgeon Handles
- Mounting Areas: for speakers;
- access to controller front panels;
- access to PC and HERMES™ Control Center;
- mounting shelves for housing

Control Units

Industry Standard Mechanism - Easy Sterilization

   • Incorporates mechanism design based on standard flushing port and push-pull rod technology, the same makeup as industry-standard endoscopic equipment.

      • Provides easy sterilization.

Instrument Reusabilty

• Uses robust, reusable instruments, built to withstand the rigorous OR environment.

Instrument and Port Size

• Offers unparalleled precision through 3.5 to 5-mm instrument and endoscope accommodation.

Wide Array of Instruments

• Offers a suite of more than 40 ZEUS®-compatible instruments, available in a variety of shaft diameters, from industry leaders Scanlan, Storz and US Surgical.

Quick Instrument Changes

• Incorporates a quick-change mechanism to seamlessly swap instruments and safely guide the placement of the instrument tips.

Console Placement

• Provides total flexibility in overall console placement, easily converting from setup directly at the operating table to setup as a physically removed console.

Rapid Setup

• Takes less than 15 minutes to set up.

Visualization

• Designed to adapt to individual surgeon preferences in viewing modes, permits both 2D and 3D visualization and accommodates a wide variety of endoscopes and monitor setups.

Secondary Monitors

• Secondary flatscreen video monitors mount parallel to the main monitor to provide   additional patient data including vitals, image guidance reference display and a redundant view of the operative field for use with SOCRATES.

Profile

• Built lightweight for easy installation and flexible adjustment, ZEUS maintains a low profile. Its twin instrument positioning arms adhere equally to this design imperative, allowing assistant to retract, suction and irrigate during surgery.

Operation

• A user-friendly, single foot pedal provides device engagement and disengagement.

When engaged, specific controls are easily accessed using voice control and touch screen interfaces.

Microwrist Hand Controls

• MicroWrist form-fitting hand controls translate the surgeon's movements with precise scaling and hand tremor filtering.

Scaling

• Offers infinite motion scaling, without limitation to arbitrarily defined increments.

•Scaling adjustment can be accomplished using either touch screen or voice command.

Six Degrees of Freedom

• 4 Motorized

•Up and Down

• In and Out

• Shoulder: Back and Forth

• Elbow: back and forth

• 2 Floating

 Forearm: back and forth - safety function: float away to avoid ramming something

• Wrist

• 1 Fixed change in angle

• Elbow Tilt (+/- 3 degrees)

Seating Accomodation

• Ergonomic console and seat provides optimal surgeon comfort for long procedures

Repositioning

• During surgery, endoscopic and instrument positioning arms tilt with the operating table; this flexible design eliminates the need to readjust or recalibrate the arms.

Re-Indexing

• At any time, the foot pedal releases the clutch, allowing surgeons to relax and reposition   (center and re-index) their hands and arms.

Endiscopic Position Saving

• Provides the powerful capability to save 3 different endoscopic positions, retaining x-y-x axis coordinates that can be quickly and easily returned to at any time.

Voice Control

• Voice control components leverage the advantages of a sophisticated overall communication paradigm:

• individual surgeon voice modeling;

• context sensitive tree command structure;

• limited vocabulary for error avoidance;

• voice and visual feedback on command success;

• compensation for ambient OR noise.

Pendant Control

• Device control and communications options are embedded also in ZEUS portable pendant device, allowing flexible, duplicate control options that

transcend the OR's sterile boundary.

Mirror Redundancy

• Uses mirror redundancy technology at a rate of up to 1000 times per second to ensure patient safety.

3.2.3 AESOP ROBOTIC SURGICAL SYSTEM

The AESOP system employs the assistance of the Automated Endoscopic System for optical position. AESOP was the first robot to be cleared by FDA for assisting surgery in the operating room. AESOP is much simpler than the da Vinci and Zeus system. It is used by the physician to position the endoscope of a surgical camera inserted into the patient. Voice activated software allow the physician to position the camera leaving her hands free. The AESOP robotic surgical system was very complex. So that it cannot be used in operating rooms.

3.2.3.1 SURGEON BENEFITS

• Its enhanced three dimensional visualization provides the surgeon with a true three-dimensional view of the operating field. This direct and natural hand and eye instrument is similar to open surgery with all around vision and ability to 300m in and 300m out.

• Improved dexterity: It provides the surgeon with intensive operative controls.

• Greater surgical precision: It permits the surgeon to control the instrument with high accuracy. It can be simply controlled by the movement of instruments.

• Increased range of motion: Endowrist instruments are used in this surgical system. It has the ability to rotate the instruments more than 300 degrees through tiny incisions.
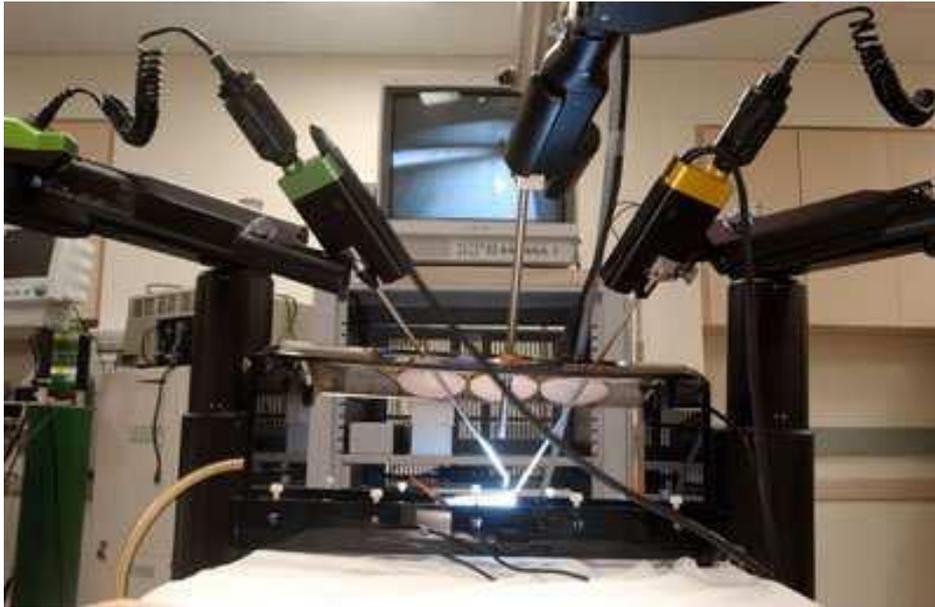
3.3 SHARED-CONTROL ROBOTIC SURGERY SYSTEMS

Shared-control robotic systems aid surgeons during surgery, but the human does most of the work. Unlike the other robotic systems, the surgeons must operate the surgical instruments themselves. The robotic system monitors the surgeon's performance and provides stability and support through active constraint.

Fig 3.3.1 A shared control robotic surgery system for heart surgery.

Active constraint is a concept that relies on defining regions on a patient as one of four possibilities: safe, close, boundary or forbidden. Surgeons define safe regions as the main focus of a surgery. For example, in orthopedic surgery, the safe region might be a specific site on the patient's hip. Safe regions don't border soft tissues.

In orthopedic surgery, a close region is one that borders soft tissue. Since orthopedic surgical tools can do a lot of damage to soft tissue, the robot constrains the area the surgeon can operate within. It does this by providing **haptic** responses, also known as force feedback. As the surgeon approaches the soft tissue, the robot pushes back against the surgeon's hand. As the surgeon gets closer to soft tissue, the instrument enters the boundary region. At this point, the robot will offer more resistance, indicating the surgeon should move away from that area. If the surgeon continues cutting toward the soft tissue, the robot locks into place. Anything from that point on is the forbidden region.

Fig 3.3.2 Robotic System.

Like the other robots we've looked at, shared-control system robots don't automatically know the difference between a safe region versus a forbidden region. The surgeons must first go through the planning, registration and navigation phases with a patient. Only after inputting that information into the robot's system can the robot offer guidance. Out of the three kinds of robot surgical system, the telesurgical approach has received the most attention.

4. SOFTWARE ARCHITECTURE OF A ROBOTIC SYSTEM

4.1 Introduction

Endoscopic surgery is a challenging technique for thoracic interventions. Its application is especially expedient in the field of heart surgery, because sternotomy or large intercostal cuts can be avoided. Therefore, the collateral surgical trauma of the patients is minimized, which results in quicker recovery of patients. In addition, the time of hospitalization and the infection rate can be reduced. Therefore, patients massively profit from this endoscopic treatment option. On the other hand, surgeons have to cope with increasingly complex working conditions, but the design of intuitive user interfaces can help to overcome these barriers. Since endoscopic surgery is performed through a small port or "key-hole" in the patient's chest surgeons must learn to operate with unfamiliar and often awkward surgical instruments. All movements are performed using "P" as fulcrum and visual impressions of the field of operation is provided by means of an endoscopic camera.
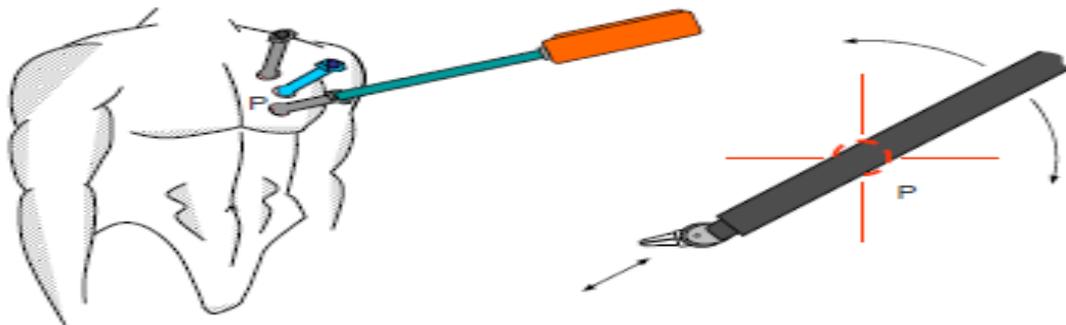
Fig 4.1 Location of endoscopic ports for instruments and camera.

Hence, the techniques of endoscopic surgery have been applied uncommonly particularly in the field of heart surgery. An important step to push this technology was the introduction of telemanipulation, which was especially designed to overcome the fulcrum effect of endoscopic instruments. The surgeon no longer operates the instruments directly, but they are driven by a special device with a Cartesian user interface, which surgeons can handle as usual, i.e. like instruments for open surgery. Commercial examples for such systems are the *daVinci* and *ZEUS* systems (the latter has been discontinued). They are good examples of how the proper design of user interfaces can push forward new technologies like minimally invasive and endoscopic surgery. They offer as much freedom of movement as the hand of the surgeon in conventional open surgery, thus providing six degrees of freedom instead of

four, like conventional endoscopic instruments. In addition, they assist the surgeon with motion scaling, tremor filtering and a stereo vision interface at the input console. Surgeons can now operate with a surgical mechatronic assistant in a comfortable, dextrous and intuitive manner. Despite the obvious potential advantages of robot assisted surgery, most researchers and surgeons in this area agree that the lack of a haptic interface is a crucial drawback of currently available systems. The inability of the operator to sense the applied forces causes increased tissue trauma and frequent suture material damage. The systems are telemanipulator with no Cartesian position control (the control loop is implicitly closed by visual surveying of the surgeon). In addition, it is not possible for users from other fields to program new trajectories for those devices. Therefore, the main research interests are the construction and evaluation of force sensory / force feedback and the development of an easy-to-use interface for trajectory planning.

4.2 Materials and Methods

Fig 4.2 System setup

An experimental system for robotic surgeryis developed with four robotic manipulators which are controlled by two PHANToM devices (from Sensable Inc). This device is available in different versions with different capabilities. Here the version Premium 1.5 is used, which provides a 20×25×40 cm workspace that is large enough for surgical procedures. The user controls a stylus pen that is equipped with a switch that can be used to open and close the micro-grippers. The most interesting feature of the employed PHANToM devices is their capability of displaying forces to the user. Forces are fed back by small servo motors

incorporated in the device. They are used to steer the stylus pen in a certain direction. This creates the impression of occurring forces, while the user is holding the pen at a certain posture. T he PHANToM device can display forces in all translational directions, while no torque is fed back. In order to be able to display realistic forces during operations, the instruments are equipped with force sensors. Since the shaft of the surgical instrument is made of carbon fiber, force sensors have to be very sensitive and reliable. Therefore, strain gauge sensors are applied, which are employed in industrial force registration. For efficient telemanipulation, it is critical to have a 3D-interface providing a clear view of the operating area. In order to allow such a feature, an additional robot with a 3D endoscopic camera is equipped. Like the surgical instruments, this camera can also be moved by means of trocar kinematics and can either be actively controlled by the operator or automatically tracked by the system. To enable stereo vision an integrated optical system with a semi transparent mirror is used that displays for each eye the corresponding camera view.

4.3 Planning Interface

Apart from the manual user interface (master console with PHANToMs), the system also comprises an interface for offline and real-time trajectory planning. The central part of this tool is a virtual emulation of the system where the user can easily manipulate its state. In the figure a robotic arm of the system is selected. Items in the scene can either be selected by directly clicking on them or by choosing them from the scene browser on the upper right side of the GUI. The scene browser can be used as a basic CAD program. It is possible to insert new primitives (like cones, spheres, cubes etc.) or VRML objects, e.g. an endoscopic instrument. If these objects are selected, a context menu for the corresponding parameters is displayed. Therefore, as shown in figure, a corresponding context menu to adjust the different joints of the robot is displayed. Each context menu of an object contains functionality to translate or rotate the object.
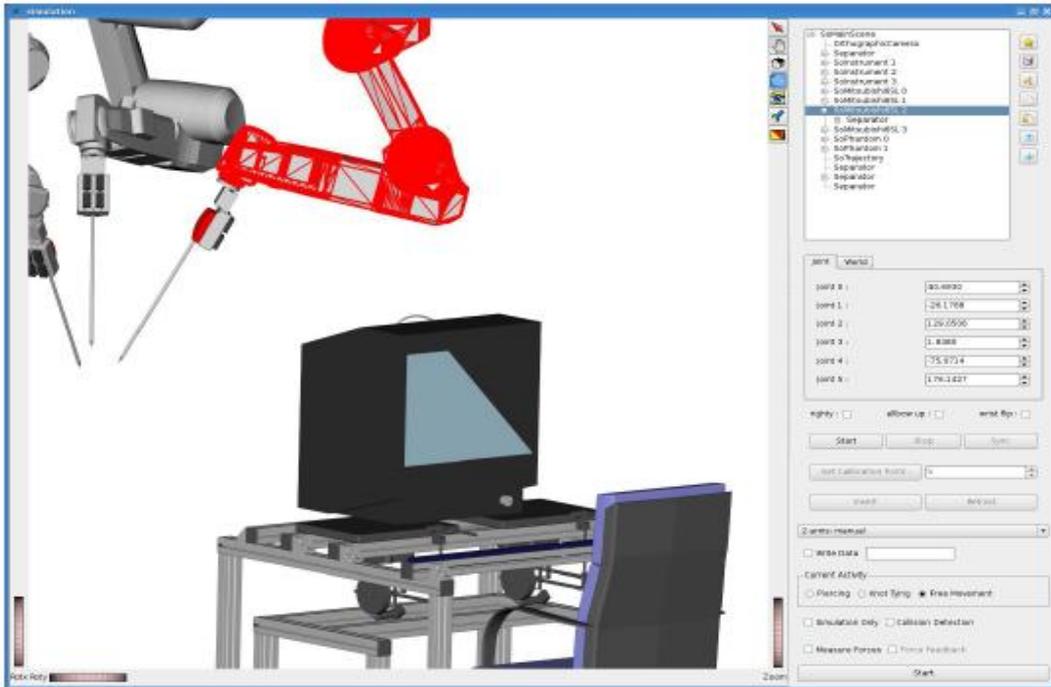
Fig 4.3.1 Graphical User Interface

With the help of the scene browser it is also possible to aggregate objects to groups, which can be manipulated on their part. It is also possible to move objects in the hierarchy of the scene graph or to remove them completely. In addition, the copy and paste functions have been implemented in order to reuse preassembled parts. The scene graph, or parts of it, can be stored to disk in order to get a permanent copy. This functions constitute an intuitive interface for users to manage different scenes and make certain modifications. All operations on the scene graph are implemented by means of the open source *Coin3D* interface from Systems in Motion AS. This is a high-level graphics language based on *OpenGL*. The GUI provides different modes of interaction with the robots or surgical instruments. As mentioned above, the robots can be moved by means of sliders; one for each joint of the robot. In addition, the robots can also be moved in Cartesian space, i.e. linear translations in x,y and z direction and corresponding rotations about these axes. After the configuration of the robot has been determined, Cartesian movements will be mapped onto joint angles by a specific inverse kinematics. The same applies to the minimal invasive instruments, which require a special inverse kinematics if moved in Cartesian space (so-called port kinematics). Port kinematics arranges for movements of the instrument about a small incision in the patient's body and is indispensable for robotic applications in endoscopic surgery. Since each instrument is linked to a dedicated robot, any movement that changes the position of the instrument's base will consequently induce corresponding movements of the robot where the base is attached to. So

far, we can use this interface to move the robots or instruments from one posture to another. This can either be executed in real-time or offline. In real-time mode, the robot directly follows the movements that are instructed by the GUI sliders. Since this is quite dangerous (particularly in Cartesian mode: small slider changes can result in wide-ranging robot movements), this feature is usually disabled during normal operation. In contrast, offline operation provides more safety. After adjusting the posture of the robot by the sliders in offline mode, the robot will not move until the user has acknowledged the new stage. For more sophisticated trajectories, as they may occur in robotic knot-tying, this kind of interface for point-to-point movements will not be sufficient. Therefore, a planning interface based on keyframing has been developed. Speaking of key framing regarding trajectory planning, the robots are moved to certain consecutive positions, which are interpreted as keyframes. Afterwards, certain policies (e.g. linear or spline interpolation) are applied to generate all other points of the trajectory lying in between those key frames. There are two different modes of moving on a trajectory with keyframes: one is to stop at each key frame, the other, more complex possibility is to perform a continuous movement through all key frames between start and end.
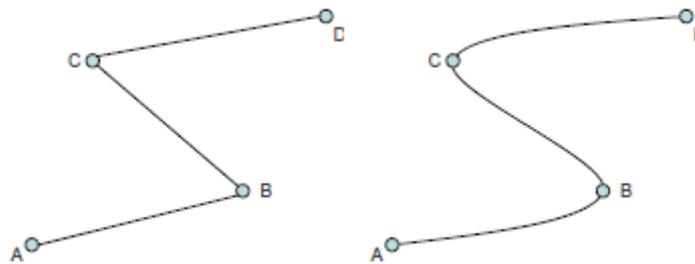

Fig 4.3.2 Linear and spline interpolation between keyframes.

Being the most difficult possibility, we restrict ourselves to the description of continuous movements via spline interpolation. Every robot needs a certain time for acceleration after starting and for deceleration before stopping. Otherwise it is not possible to achieve jerk free motions. Another prerequisite for the application is that keyframes occur at certain points in time which have to be met exactly i.e. if the robot starts in point A , it will first accelerate to a certain speed which depends on the time when point B has to be reached (figure). Accordingly, there is a fixed time to move from B to C. Therefore, the robot will have to adapt its speed after leaving point B. For calculating the speed during acceleration and decelerations, we have employed the functions *va(t)* and *vb(t)*, respectively:

$$v_a(t) = \frac{v_0}{1 + e^{n\left(1 - \frac{2t}{t_a}\right)}} \qquad v_b(t) = \frac{v_0}{1 + e^{-n\left(1 - \frac{2t}{t_b}\right)}}$$

Those are sigmoid functions shifted along the positive *t*-axis. The factor *n* changes the acclivity of the curve, which reaches its maximum at $t = \frac{t_{max}}{2}$. The time needed for acceleration and deceleration is denoted as *ta* and *tb*, respectively. Another nice feature of these functions is, that the area underneath the curve (i.e. the traveled path) amounts to $\frac{1}{2}t_a v0$. Therefore, we can easily determine the residual speed *v0*, given a certain path length and frame time (the same holds for deceleration). Determining the path length is easy for linear keyframe interpolations, but analytically not feasible for splines (in that case Hermite splines). Therefore, it is guaranteed that the next keyframe will be reached at the right time and with the right velocity. The only thing left to do for the user is to set the keyframes on a timeline within the GUI. All trajectories can be displayed in the simulation environment and a preview of the corresponding movements is possible. If collisions occur, it is not possible to execute the trajectory before it is safely replanned.
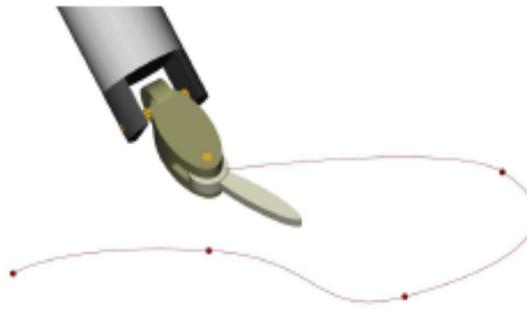

Fig 4.3.3 Display of the keyframes and the calculated trajectory

4.4 Software Architecture

The software is independent from a specific operation system. Currently, the system is based on a Linux 64bit platform, but it may be compiled for other platforms without major changes as well. All modules, including the HAL and all superordinate parts, are written in plain C++ using only standard extensions like STL, which are available for most platforms. The code contains only types, which are independent from a specific word-length, and therefore, will run on both 32bit and 64bit systems. Although the software profits from running on a 64bit system,since the accumulated errors within the inverse kinematics are significantly reduced. All libraries used in the software are available as public domain source code and may be compiled for various operating systems. In detail, we use *MySQL* as database, *Qt* for constructing the GUI, *Coin3D* for visualizing the 3D models and *GNU GSL*

provides some of the scientific functions like SVD. The only parts of the software, which are platform dependent, are the drivers for the PHANToM devices and the CAN-bus interface. However, both are also available for other platforms.

In order to guarantee scalability and quick response times, the architecture of the software is based on multi-threading. Thus, all important control loops of the software are implemented as threads (platform independent *POSIX* threads). Every manipulator added to the scene has to provide its own control thread, which interacts with the corresponding robots and instruments. These threads are set to real-time priority in order to guarantee accurately timed transmission of joint angles. They are scheduled to be executed every 3*ms*. Therefore, new joint angles arrive at the robot at least once in a control cycle of 6.8*ms*. If more than one set of joints arrives during a cycle, additional values are simply omitted by the controller and will cause no unexpected behaviour. The same strategy applies to the control threads of the PHANToM devices, which arrange for proper acquisition of postures and realistic force feedback. Although being implemented as real-time threads, they are set to a lower priority as the control threads. This is due to the fact that a violation of the timeliness of the control threads will lead to a system crash, while a reduced timeliness of the PHANToM threads will only induce minor jerks regarding the movement of the controlled robots and the force feedback. The thread for interactions with the user interface is set to non-real-time priority, since no interactions are required during manual operation of the system (with all other threads activated) and a timely display of the 3D models is not critical. Since the threads have to interchange data with each other (e.g. the PHANToM threads provide data for the control threads of the robots, or the collision detection must be able to stop all robot threads), a central class called ControlUnit has been implemented providing shared access. In addition, this class also provides an interface to the *MySQL* data base in order to store trajectories and other features. Due to the one-way flow of data, mutual exclusion of data access is not necessary. This leads to a significant increase of speed and intrinsically avoids starvation of threads. The architecture of the software is mostly based on the model-view-controller design pattern. This concept is explained on the basis of the classes, which have been implemented in order to interact with the *Mitsubishi* robots. The model is realized by the class Mitsubishi6SL and contains all functionality for on and offline interactions with the robot (e.g. establish a connection to the controller, start servos, set joints, etc.). The view is implemented as a 3D model, which is going to be displayed in the simulation environment.
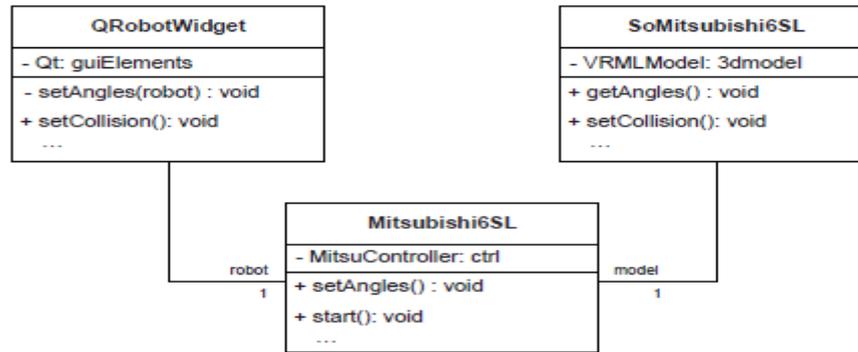
*Fig 4.4.1*Model-View-Controller (MVC) architecture of the robot interface.

This is the only part of the robot's interface depending on the *Coin3D* API. Therefore, the corresponding class, SoMitsubishi6SL, contains a VRML model of the *Mitsubishi MELFA 6SL*, functions for changing its angles and methods to visualize the collision detection. This class contains a pointer to the model (Mitsubishi6SL) in order to update the angles in the 3D view. In contrast, the model contains no pointers to the view class in order to allow for implementations of the control software without 3D graphics, or even without any GUI. Thus, the model also contains no pointer to the controller class, QRobotWidget. The capital "Q" indicates that this (and only this) part of the software was implemented with *Qt*, a widespread API for implementation of GUIs. This class contains the context menu for robot interaction (see above), thus, providing sliders for adjustment of angles, Cartesian control, or movements in tool frame. In addition, the menu exhibits some buttons to activate functions of the model (e.g. starting and stopping the servos of the robot). The QRobotWidget-class contains no direct pointer to the model (Mitsubishi6SL), but a pointer to an abstract class. Therefore, it is easy to exchange the robot model without greater modifications. This abstract robot class can be implemented by various types of robots. While the robot-specific parts (e.g. low-level communication with the controller) are hidden within these specific classes, they have to implement standardized functions for interaction with certain GUI elements. For example, every class implementing Robot has to provide functions for starting and stopping the servos, and for the adjustment of angles. A similar concept used for the view of a robot. They are all derived from a *Coin3D* base class, SoRobot.
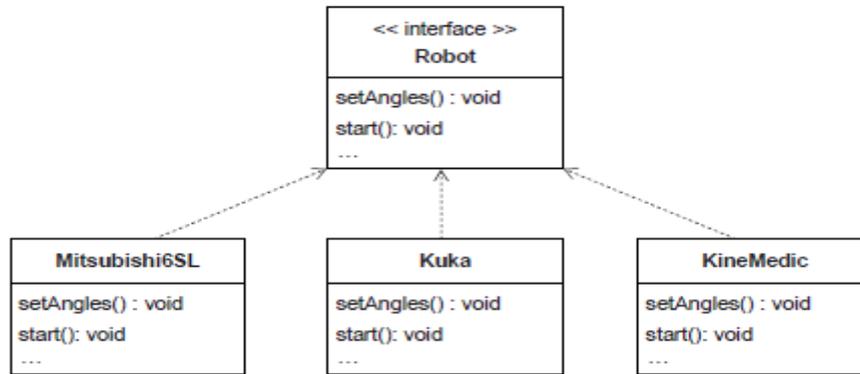
Fig 4.4.2 Different models of robots are implementations of the same abstract class

4.5 Conclusion

This is the software platform of a robotic system for minimally invasive surgery. In order to provide an intuitive user interface a keyframing approach has been adopted like it is known from computer animation. All relevant motion parameters, which are usually difficult to determine, will be calculated automatically. Therefore, the operator can concentrate on task-specific work, e.g. planning the trajectory for endoscopic knot-tying. In addition, a flexible software architecture enables an easy adaption of the system to new hardware technology. At least in the field of robotic surgery this technique has advanced the acceptance of robots in the operating room by surgeons. In the near future , the possibility to integrate preoperative, patient centered image data like CT or MR scans, in addition to, plans of augmenting the user interface by haptic concepts like virtual fixtures are being considered.

5. APPLICATIONS

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.

Gastrointestinal surgery

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

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, pelvic prolapse, 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. It can also be used for tubal re-anastomosis, hysterectomies and ovary resection.

Neurosurgery

Several systems for stereotactic intervention are currently on the market. MD Robotic's NeuroArm is the world's first MRI-compatible surgical robot. Surgical robotics has been used in many types of surgical procedures including complement-image-guided surgery and radiosurgery.

Orthopedics

The ROBODOC system was released in 1992 by the Integrated Surgical Systems, Inc.Surgical robotics has been used in many types of orthopedic surgical procedures including total hip arthoplasty: femur preparation, acetabular cup replacement, knee surgery and spine surgery.

Pediatrics

Surgical robotics used in 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.

Radiosurgery

The CyberKnife Robotic Radiosurgery System uses image-guidance and computer controlled robotics to treat tumors throughout the body 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.

6. ADVANTAGES

Robots in the field of surgery have dramatically changed the procedures for the better. The most significant advantage to Robotic Surgery to the patient is the decrease in pain and scaring. By using cameras and enhanced visual effects, doctors can make the tinniest of incisions. The da Vinci and Zeus system each use "arms" to operate. In order for these arms to get inside the body and operate, they only need a few centimeters for an incision. In fact The San Matteo Hospital in Pavia, Italy performed a Cardiac Bypass surgery that included three incisions, each about one centimeter in length. Typically in that type of surgery the incision is about 30 centimeters in length. The smallness of the incisions also causes many other advantages that make Robotic Surgery worth the risk. Due to the small and precise cuttings, the patient's hospital stay is greatly reduced. A person needs far less recovery time when they have 3- centimeter scars than when they have a scar almost 10 times as large. Also, the risk of infection or complications decreases as the incision size does. The patient mentioned earlier with the Closed Heart Bypass surgery is a terrific example. After his surgery, he was cleared by his surgeon Dr. Mauro Rinaldi and released from the hospital after only 12 hours of recovery. The next week he was actually able to join his family on a vacation. In today's operating rooms, you'll find two or three surgeons, an anaesthesiologist 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 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 sits 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 telesurgery, which would involve a doctor performing delicate surgery miles away from the patient. The doctor doesn't have to stand over the patient to perform the surgery, and can control the robotic arms from a computer station just a few feet away from the patient. Having fewer personnel in the operating room and allowing doctors the ability to operate on a patient long-distance could lower the cost of health care in the long term. Besides the obvious rewards to the patient, Robotic Surgery is also very advantageous to the surgeon and hospital. In the ZEUS Surgical System, an "arm" on the machine is dedicated to the Automated Endoscopic System for Optimal Positioning (AESOP). AESOP is a 3D camera used in robotic surgery. It can be

zoomed in by either voice activation or pedals located at the surgeons foot. Doctors who have used this actually argue that AESOP gives a better image than in real life. This is particularly true with surgeons that have poor vision or in microscopic surgeries that deal with nerves. Also, by using the hand controls the surgeons can reach places in the body that are normally unreachable by the human hand. Finally, the clearest advantage to using robots in surgery is in long operations, that deal with nerve or tissue reconstruction. Surgeons often tire easily after performing microscopic surgery's that last hours. However, ability to be seated and have less strain on the eyes, helps doctors to control their natural flinching or nerves efficiently.

6.1 Post-Surgery
• Less scarring
• Faster recovery time
• Tiny incisions
• 0% Transfusion rate
• Shorter catheter time 5 vs. 14 days
• Immediate urinary control
• Significantly shorter return to normal
activities (1-2 weeks)
• Equal Cancer Cure Rate
• Less post operative pain

6.2 In-Surgery
• Surgeons have enhanced view
• Easier to attach nerve endings
• Surgeons tire less easily
• Fewer doctors required in operating rooms
• In turn, cheaper for hospitals.
• Smaller risk of infection
• Less anesthesia required
• Less loss of blood

7. LIMITATIONS

7.1 The Question of Safety

In comparison to robots used in the industrial sector, medical robots present designers with much more complicated safety problems. Some of the most important factors which lead to such complexity are described below:

• Human presence: In an industrial situation, there are no humans present in the application environment. Should that be necessary, safety regulations specify that the robot be de-activated while humans are in the vicinity. This greatly simplifies the safety requirements and their satisfaction. In the medical sector, however, robots are required to assist rather than to replace humans. In that respect, they must be able to work in close proximity to humans and perform well in a chaotic, time-varying environment. This requires medical robots to have rich sensory and reasoning capabilities concerning their environment, something that both pushes the current technology to the limits and presents robot designers with insurmountable obstacles.

• Fault consequences: This is closely related not only to the presence of humans near the robot, but also to the nature of the task of the robot, which typically involves a human patient. In the industrial sector, a fault can mean at most some loss of physical equipment. In the medical sector, where lives are at stake, the implications are of profound importance.

• Non-generic task: In the industrial sector, the robot is required to perform a series of movements in some pre-defined order. The object it is operating on, be it as simple as a metal pipe or as complex as a car, is not distinguished in any way, that is, the robot is not required to take account of differences on an object-by-object basis, but treats them all as being equal. When dealing with patients, however, this is not possible. Each patient has their own distinguishing characteristics, making a uniform approach inappropriate. In safety terms, this requires testing, or at least reasoning about infinitely many scenarios. Possible reasons that can lead to unsafe operation of a medical unit include flawed design, malfunction of hardware and software components, misinterpretation and incorrect or inadequate specification. As in many other applications, improving some of these parameters results in a degraded performance in other areas, while an overall increased level of safety is accompanied by an increase in cost, complexity, or both. The idea of total safety is a fallacy. Instead, different safety strategies offer different advantages (and course, disadvantages). The overall probability of error must be always kept at very low levels. Perhaps even more

important than the probability of a fault is the ability to detect that a fault has indeed occurred and prevent hazards resulting from it, that is, allow the robot to "fail safely". This usually involves shutting the robot down and removing it from the patient, and having the operation manually completed by a surgeon. As the task which the robot undertakes becomes more and more complicated, there is an increasing need for more complex hardware and software components (faster response, better accuracy, more degrees of freedom). This increases the probability of error exponentially. Software is notoriously difficult to reason about, while hardware reliability never ceases to be of prime importance. A final consideration concerning safety is, perhaps surprisingly, size. Both patients and doctors feel uncomfortable working next to medical robots which tower above the surgeon at over 7 feet and weigh in at several tens of kilograms. There is some logic behind that, however. A larger robot can usually exert more force than a smaller one, resulting in an increased amount of damage in case of a fault.

7.2 The Cost

The Robots that perform the surgeries cost around $750,000 to over $1 million. This is because they use extremely sensitive and experimental equipment that costs a lot of money. In addition to the cost of the machines the training that is needed for surgeons to learn how to use the systems is also very expensive. Because of the extreme cost of the machines at this point in time the procedures are slightly more expensive than a regular operation, but it does have its advantages. Many people in the medical field however believe that these surgeries will soon become more common and less expensive.

8. THE FUTURE

Robotic surgery is in its infancy. Many obstacles and disadvantages will be resolved in time and no doubt many other questions will arise. Many questions have yet to be asked; questions such as malpractice liability, credentialing, training requirements, and interstate licensing for tele-surgeons, to name just a few. Many of current advantages in robotic assisted surgery ensure its continued development and expansion. For example, the sophistication of the controls and the multiple degrees of freedom afforded by the Zeus and da Vinci systems allow increased mobility and no tremor without comprising the visual field to make micro anastomosis possible. Many have made the observation that robotic systems are information systems and as such they have the ability to interface and integrate many of the technologies being developed for and currently used in the operating room. One exciting possibility is expanding the use of preoperative (computed tomography or magnetic resonance) and intraoperative video image fusion to better guide the surgeon in dissection and identifying pathology. These data may also be used to rehearse complex procedures before they are undertaken. The nature of robotic systems also makes the possibility of long-distance intraoperative consultation or guidance possible and it may provide new opportunities for teaching and assessment of new surgeons through mentoring and simulation. Computer Motion, the makers of the Zeus robotic surgical system, is already marketing a device called SOCRATES that allows surgeons at remote sites to connect to an operating room and share video and audio, to use a "telestrator" to highlight anatomy, and to control the AESOP endoscopic camera. Technically, many remains to be done before robotic surgery's full potential can be realized. Although these systems have greatly improved dexterity, they have yet to develop the full potential in instrumentation or to incorporate the full range of sensory input. More standard mechanical tools and more energy directed tools need to be developed. Some authors also believe that robotic surgery can be extended into the realm of advanced diagnostic testing with the development and use of ultrasonography, near infrared, and confocal microscopy equipment. Much like the robots in popular culture, the future of robotics in surgery is limited only by imagination. Many future "advancements" are already being researched. Some laboratories, including the authors' laboratory, are currently working on systems to relay touch sensation from robotic instruments back to the surgeon. Other laboratories are working on improving current methods and developing new devices for suture-less anastomoses. When most people think about robotics, they think about

automation. The possibility of automating some tasks is both exciting and controversial. Future systems might include the ability for a surgeon to program the surgery and merely supervise as the robot performs most of the tasks. The possibilities for improvement and advancement are only limited by imagination and cost.

9. CONCLUSION

Although still in its infancy, robotic surgery has already proven itself to be of great value, particularly in areas inaccessible to conventional laparoscopic procedures. It remains to be seen, however, if robotic systems will replace conventional laparoscopic instruments in less technically demanding procedures. In any case, robotic technology is set to revolutionize surgery by improving and expanding laparoscopic procedures, advancing surgical technology, and bringing surgery into the digital age. Furthermore, it has the potential to expand surgical treatment modalities beyond the limits of human ability. Whether or not the benefit of its usage overcomes the cost to implement it remains to be seen and much remains to be worked out. Although feasibility has largely been shown, more prospective randomized trials evaluating efficacy and safety must be undertaken. Further research must evaluate cost effectiveness or a true benefit over conventional therapy for robotic surgery to take full root.

10. REFERENCES

[1] Workshop on Robot Middleware towards Standards, International Conference on Intelligent Robots and System (IROS'04), Sendai, Japan, 2004, http://www.is.aist.go.jp/rt/events/20040928IROS.html.

[2] H. Bruyninckx: Open robot control software: the OROCOS project, Procedings of the IEEE 2001 International Conference on Robotics and Automation (ICRA'01), volume 3, pages 2523–28, Seoul, Korea, 2001,
http://www.orocos.org.

[3] A. Brooks, T. Kaupp, A. Makarenko, A. Oreb ¨ ack, S. Williams: Towards Comonent-Based Robotics , Proceedings ot the 2005 IEEE/RSJ Interna- tional Conference on Intellegent Robots and Systems (IROS'05), Alberta, Canada, 2005.

[4] B.P. Gerkey, R.T. Vaughn, K. Stoy, A. Howard, G.S. Sukhatme, M.J. Mataric: Most Vauable Player: A Robot Device Server for Distributed Control, Proceedings of the IEEE/RSJ International Conference on Intel- ligent Robots and Systems (IROS'01), pages 1226–1231, Wailea, Hawaii, 2001.

[5] C. Cote, D. Letourneau, F. Michaud, J.-M. Valin, Y. Brousseau, C. Raiev- sky, M. Lemay, V. Tran: Code Reusability Tools for Programming Mobile Robots, Proceedings of the 2004 IEEE/RSJ International Conference on Intellige Robots and Systems (IROS'04), pages 1820–1825, Senda, Japan, 2004.

[6] N. Karlsson, M.E. Munich, L. Goncalves, J. Ostrowski, E. Di Bernado, P. Pirjanian: Core Tehnologies for service Robotics, Proceedings of the 2004 IEEE/RSJ Internatiol Conference on Intelligent Robots and Systems (IROS'04), Senda, Japan, 2004.

[7] T. Scherer: A mobile service robot for automisation of sample ta- king and sample management in a biotechnological pilot laborato- ry, University of Bielefeld, Ph.D Thesis, 2005, http://bieson.ub.uni- bielefeld.de/volltexte/2005/775/.

[8] V. Hayward, J. Lloyd: RCCL User's Guide, McGill University, Montre'al, Qu'ebec, Canada, 1984.

[9] W.T. Townsend: The BarretHand Grasper - programmably flexible part handling and assembly, Industral Robot: An international Journal, Vol. 27, Nr. 3, pp.181-188, 2000.

[10] D. Westhoff, H. Stanek, T. Scherer, J. Zhang, A. Knoll: A flexible framwork for task-oriented programming of service robots , Robotik 2004, VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik, VDI- Berichte (ISBN 3-18-091841-1), Munich, Germany, 2004.

[11] The Real-Time Java Expert Group: The Real-Time Specification for Java (RTSJ), 2002, http://rtsj.dev.java.net.

[12] M. H ¨ user, T. Baier, J. Zhang: Learning of demonstared Grasping Skills by stereoscopic tracking of human hand configuration, To Appear, IEEE International Conference on Robotics and Automation, Orlando, Florida, May 2006.