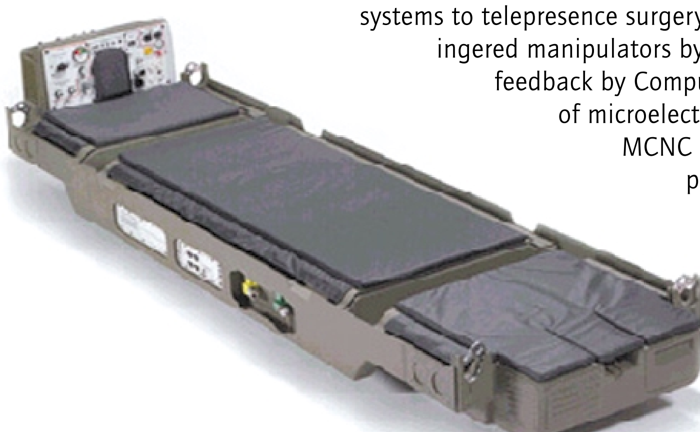
OVERVIEW

Current technology only permits the medic to give the basic life-saving care in the far forward area, and no capability for advanced care or surgery on the battlefield. Recent advances in robotics, miniaturization and telemedicine will permit the surgeon to return to the far forward battlefield—through telepresence surgery. The SRI International telesurgery system consists of the central surgeon's console, which can be located in the MASH, and the remote robotic arms, which can be located in Foster-Miller's medical forward advanced surgical technology (MEDFAST) vehicle. Thus, once the medic places the wounded soldier in the MEDFAST, together the medic and surgeon can perform telesurgery on the casualty, just enough surgery to stop exsanguinating hemorrhage. The casualty can then be placed in the Life Support for Trauma and Transport (LSTAT) by Northrup Grumman, a fully functional intensive care unit (ICU) with ventilator, IV fluid therapy

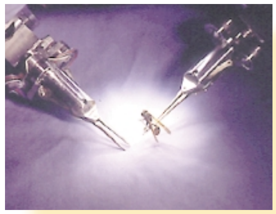
infusion, oxygen, complete monitoring and telemedicine capability back to the MASH or upper echelons. Some of the functions can be remotely controlled, such as the ventilator or IV fluid administration, to provide adjustment during evacuation. The SRI telesurgery system has been licensed to Intuitive Surgical, Inc., and a similar robotic manipulator system by Computer Motion, Inc., has completed development with funding beyond the initial DARPA system. Both telesurgery systems are performing surgery on patients today, including very intricate minimally invasive cardiac surgery on the beating heart. The LSTAT is a commercially available system.

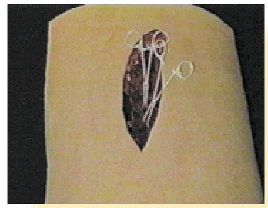
The telepresence surgery system consists of a surgeon's console with video monitor and handles for input devices, giving the surgeon the sense of actually being at the site of surgery. The remote manipulators afford a high level of accuracy and dexterity, even being able to enhance the surgeon's precision beyond the limitations of human physical control. An ultra precision system by MicroDexterity Systems, Inc. can scale down the surgeon's motion 100 to 1, resulting in an accuracy of 10 microns, which is 20 times beyond the limits of human control. A number of highly experimental subsystems to telepresence surgery have been investigated, including ingered manipulators by Daum Hand, Incorporate, tactile and audio feedback by Computer Aided Surgery, Inc., and the exploration of microelectrical machine systems (MEMS) actuators by MCNC Electronics Technology and electroactive polymers as artificial muscles (Brock Rogers Inc. and Carol Becker of University of San Diego). Also, using MEMS actuators at Massachussetts Institute of Technology (MIT), a tiny experimental micro-robot to replace an endoscope was prototyped.

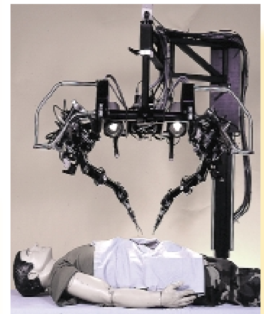


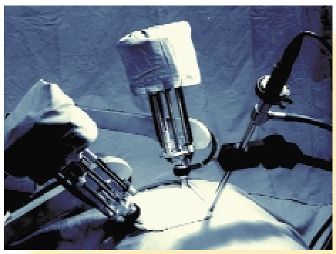
Telesurgery System

Development of a Telepresence Surgery System


Microsurgery


Simulation and training


Remote surgery


Minimally invasive surgery


Telepresence surgeon's workstation (TSW)

Project Summary

In the first project, SRI has developed, fabricated, delivered, and demonstrated a prototype advanced tele-presence surgery system that enables a surgeon, located in a mobile army surgical hospital (MASH) unit or base hospital, to carry out emergency surgical procedures on soldiers in an armored mobile surgical vehicle in the combat zone. The completed system consisted of three major components: (1) A mobile remote surgery unit (RSU) installed in an armored vehicle. Dubbed the Medical Forward Area Surgical Telepresence (MEDFAST) system, it comprises a medic-positionable pod above the surgical table, on which are mounted two 6-degrees-of-freedom (DOF) slave manipulators with interchangeable surgical instruments, a pair of high-resolution video cameras (to provide a stereoscopic image pair), and additional (low-band width) video cameras to provide a panoramic view of the MEDFAST vehicle interior. (2) A telepresence surgeon's workstation (TSW). The TSW includes a pair of 6-DOF force-feedback master manipulators, a high-resolution stereographic display for viewing the surgical field, and auxiliary monitors for viewing the assisting medic and the inside of the MEDFAST vehicle. (3) A high-data-rate, low-latency, two-way, digital, microwave communication link between the MEDFAST and the TSW. The communication link operates over a distance of up to 5†km and includes subsystems for video digitization, compression, and encoding of all signals (video, servo commands, audio, patient monitoring information), as well as modulation, demodulation, and microwave transmission.

In the second project, Telepresence Surgery Simulation, SRI adapted and expanded the Telepresence Surgery System so that it could serve as a Simulation Platform, a surgeon's interface to virtual reality (VR)-based surgical simulation and training models. The system also serves as a software and hardware platform that allows surgeons to test, evaluate, and guide development of simulation models.

In the third project, SRI provided USUHS with a complete 6-DOF Telesurgery system comprising a TSW, RSU, and system control electronics. SRI fabricated and assembled the system, installed it at USUHS, provided technical support for system operation and maintenance. We also installed system upgrades that were subsequently developed under the grant.

Technology Transfer

In July 1997, SRI delivered a complete 6-DOF MEDFAST system (comprising a TSW, RSU, and system control electronics) to the Uniformed Services University of the Health Sciences in Bethesda, MD. To provide increased access to the SRI Simulation Platform, in June 1999 we installed an identical platform at USUHS where it will form part of their new Simulation and Readiness Program. The system now enables surgeons and medical students to interact with computer-based surgical simulation and training models using the TSW. The system is licensed to Intuitive Surgical Inc. as a commercial product.

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Telerobotic Surgical System

Development of a Force-reflecting Laparoscopic Telemanipulator

Project Summary

Current generation robotic and telesurgical systems are extremely complex, large devices. This project has the goals of reducing the size, weight, number of assembly parts, and power requirements in order to drive down the manufacturing costs, increase reliability and affordability of telesurgical systems.

The Brock Rogers Surgical, Inc., telerobotic surgical system is a fully functional telesurgical system capable of robotic-performing minimally invasive surgery at remote locations. At less than 10 pounds per manipulator, this telesurgical system is small, lightweight, robust, and uniquely suited for field deployment. The telemanipulator integrates robust instrument position mechanics with interchangeable surgical end-effectors configured as standard laparoscopic tools. The system provides instrument motion with seven degrees of freedom +/− 90 degrees of rotation in the pitch, yaw and roll axes, as well as +/− 90 degrees of articulation in the jaws of the instruments. Supporting electronics subassemblies and software control algorithms were also developed and optimized for surgical teleoperation. Task-level control software was developed that provided a systematic means of controlling the instrument under network time delays. Requirements of sterility were addressed through a sealed coupling mechanism designed to provide a convenient and rapid tool exchange. In vivo evaluations demonstrated the capability of the prototype device to perform simple, clinically valuable techniques that can be used for remote investigation and treatment of common battlefield injuries. The telerobotic system, as shown above, can be used in a non-remote application to take advantage of the enhanced dexterity and precision of the core instrument guidance technology.

Technical Transfer

The Brock Rogers Surgical, Inc., is completing testing and evaluation of the completed system and employing conventional business practices to commercialize their product.

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Daum Hand

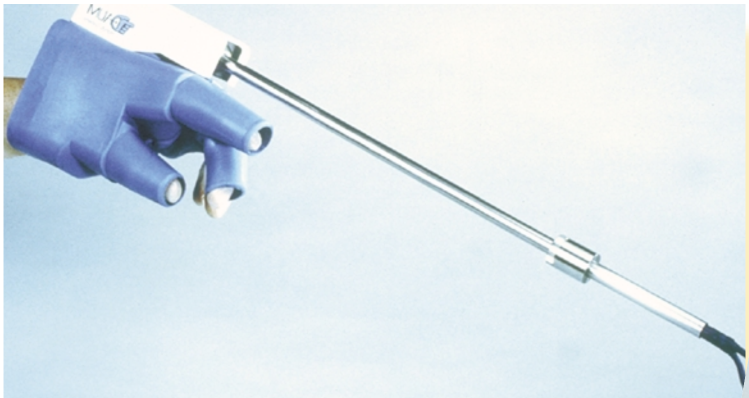

Figure 1

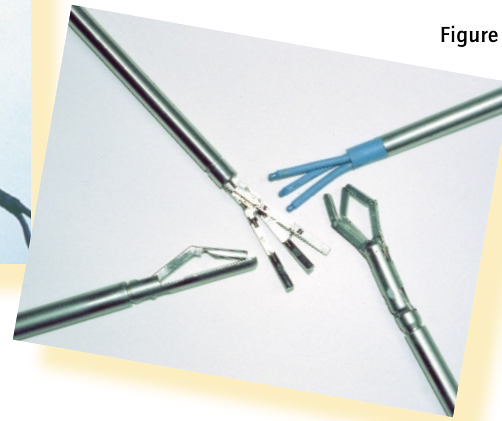

Figure 2

Surgical Robotic Hand

Project Summary

In order to improve the performance of minimally invasive surgical procedures, Daum, Inc., has developed a unique technology which provides a miniature three-fingered grasper to mimic the human hand for doing surgery inside body cavities. This instrument enables surgeons to utilize near-natural hand movements in "keyhole" surgery through the actions of the endoscopic "hand" attachment.

Existing laparoscopic equipment uses a trigger-type activation mechanism, which results in limitations in terms of dexterity and the angle of surgical approach. The principle of the Endohand is quite simple. The surgeon's hand fits inside a "glove" attached to a rod, which passes down the trocar to the manipulative fingers (Figure 1) allowing the surgeon to reach areas previously inaccessible to the human hand. Clinical feedback to date has indicated that this can reduce surgery time and increase accuracy. This device can be easily applied to any endoscopic operation and is not limited to one specific procedure.

A second-generation system prototype was designed to separate the glove from the manipulator fingers (Figure 2) and to allow the manipulation of the 3-fingered grasper through a computer interface. This has been successfully demonstrated in the laboratory, and current negotiations with robotic and telesurgery system manufacturers are in progress to incorporate the manipulator into existing robotic surgery systems.

Technology Transfer

A patenting and intellectual property company, BTG, is currently commercializing the Endohand technology for minimally invasive surgery applications.

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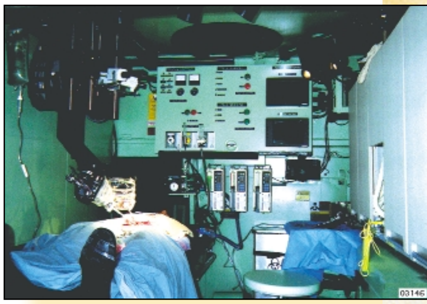
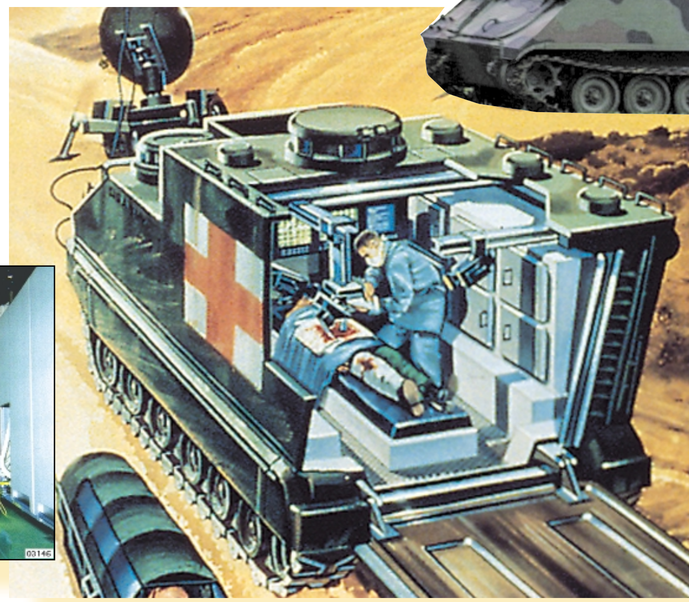
MEDFAST

MEDFAST Systems Integration of Remote Therapeutics





Project Summary

The goal of the Medical Forward Advanced Surgical Telepresence (MEDFAST) program has been to develop a systematic methodology to improve the delivery of advanced combat casualty care to the forward battle area. The MEDFAST system was to be the skeleton for the integration of enhanced conventional medical and surgical support systems with developmental diagnostic and trauma treatment systems, including telesurgery and telemedicine. MEDFAST also has had high dual use versatility in civil emergency, disaster, and EMS support roles.

In the initial conceptual implementation the MEDFAST functions were incorporated into an M577 Armored C2V. This configuration was demonstrated at the Association of the U.S. Army (AUSA) exhibition (Oct 94), National Forum on Telemedicine (Apr 95) and shown to senior military and civilian DOD staff at the Pentagon (Jun 95). This armored vehicle integrated enhanced conventional medicine (casualty status monitoring, respirator & O2, suction, infusion technologies, electrosurgery, anesthesia and LSTAT interfaces); telemedicine (real time imaging [x-ray], video casualty assessment, data links, PSM interfaces); and telesurgery (direct tele-operated surgical intervention).

The MEDFAST capabilities have since been repackaged into a vehicle independent stand-alone configuration. This design iteration utilized Casualty Care and Treatment Modules. These modules provide a "Tool Box" of enhanced casualty care capabilities. Levels of capability from basic casualty transport to lifesaving trauma surgery (both conventional and telesurgery) can be achieved by the simple addition of specialized modules to a baseline system. MEDFAST can turn any platform (including a tracked or wheeled vehicle, rotary and fixed wing aircraft, naval vessel, tactical shelter, ISO container, building or aid station site) into a high-level casualty care facility. The basic module package is configured into the same volume and shape as a standard NATO stretcher (with patient) for mounting into conventional stretcher support frames, which obviates the requirement for a specialized mounting system.

This development has been pursued within a Virtual Design Environment. We modeled the MEDFAST systems in a synthetic environment, designed to interface with DARPA's human avatar, in which a combat medic can conduct casualty care procedures utilizing the full range of VR tools (visual, tactile, aural, spatial, relational, functional, etc.). This approach provides for real-time design validation based on "operational" experience.

Technology Transfer

Prototypes of both the M577-based and modular MEDFAST systems were demonstrated for national audiences. Senior DARPA, BUMED, and NAVSEA staff viewed the Virtual Reality simulations. Commercial interests in both methodologies have been pursued, but without success at this time.

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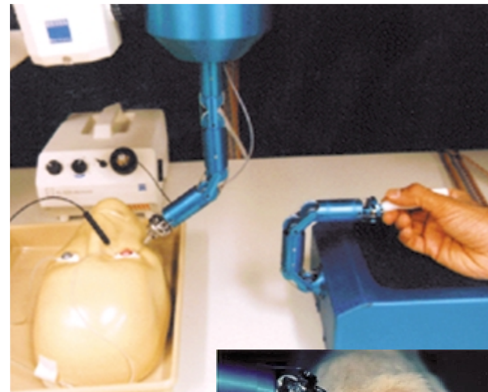
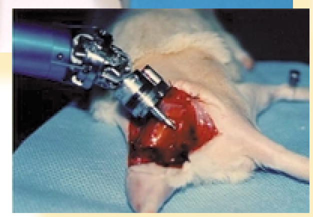
CHARLES

Microdexterity Robotic Arm

Integrated Remote Patient Care System





Project Summary

To improve the manual skills of surgeons, the project PI introduced the concept of surgical dexterity enhancement several years ago to overcome the limitation that software cannot control conventional robotic arms, geared, or cable-driven robots to achieve the mandatory, high band width force control. A novel, proprietary, position- and force-controlled parallel robot called ParaDex was developed, in part funded by this program. The device was intended for use as high band width haptic interface as well as a force-controlled, direct drive, seven degree-of-freedom, very high precision robot. The device has 1/100 the inertia, 1/1000 the friction, and six times the precision and stiffness of competitive designs. By May 1999 a hybrid position and force-controlled master-slave system was demonstrated with the predicted performance. Two very large versions of the robot were built for a NIST ATP program for automotive powertrain assembly. These systems have 5-micron positioning performance, a 75-pound payload, and very high band width force control. A next generation system called MicroDex, is a hybrid serial-parallel, direct drive, position and force-controlled system. MicroDex will be used for neuro, spine, microsurgical, cardio-thoracic, and dexterity-demanding abdominal procedures.

Technology Transfer

ParaDex will be commercialized as a force-controlled industrial assembly robot to address wrist, elbow, and shoulder injuries. DOE is investigating the use of ParaDex for hazardous material applications.

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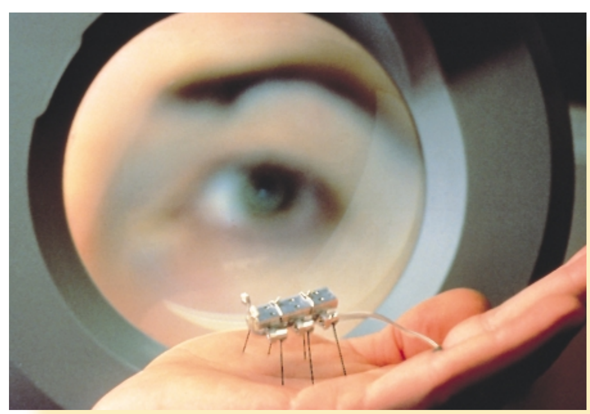
FLYNN

Micro Robot

Development of an Autonomous Endoscope



Project Summary

The goal of the feasibility study was to prototype a micro robot which can replace an endoscope and navigate within the intestines. Recent advances in micro-electro mechanical systems (MEMS) technology provides microsystems to miniaturize robotic components. Innovative control programming, such as subsumptive architecture, provide autonomous control through simple behaviors.

A number of different micro-robot models were created in order to achieve a design which would be able to navigate a tubular structure. An early model with legs driven by piezoelectric motors could navigate a maze on a flat surface, but not in a tubular structure or bovine intestine. Numerous other designs, such as wheels, tracks, inchworm, paddles etc. were tested; however, the basic problem of achieving enough power from the micro-motors defeated achieving adequate mobility. Success will have to await the emergence of motors or actuators which are robust enough to generate enough power to propel the device in the harsh environment of the body.

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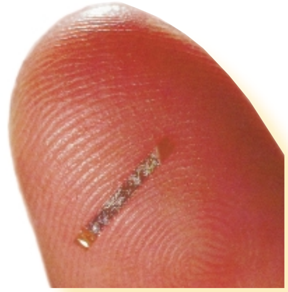
MEMS Micromuscles

Integrated Force Arrays for Specialized Robotics



Project Summary

Novel methods of actuation are needed to provide the next generation of microrobots with manipulators and actuators. In analyzing human muscles, the actin-myosin complex performs a translational action using cross-linking. By mimicking this natural mechanism using MEMS technologies, innovative actuators can be constructed.

The Integrated Force Array (IFA) is a MEMS actuator which consists of an array of deformable capacitors. The IFA is a scaleable technology capable of very small displacements of a few micrometers to large displacements of several centimeters, with forces comparable to muscle tissue when equal volumes are compared. Lifetimes of over 9×10^8 contractions were measured as well as contraction rates of up to 24,000 contractions per second. The maximum force measured was 7.59 dynes and the maximum observed motion was 610 µm. The IFAs that were fabricated and tested measured 10mm long, 3mm wide, and 2µm thick, and are appropriate for small, low force applications. The program focused on developing new methods for fabricating larger and thicker IFAs which are stronger and have larger displacements. Testing indicated that an overlapping structure wth a monolithic 25µm-thick polyimide frame surrounding the IFA that would allow a large number of actuators can be stacked in a small volume, with automatic spacing between adjacent IFAs.

Technology Transfer

Development of the IFA is continuing at MCNC. New IFAs are being fabricated for researchers at Duke University for use in a scanning ultrasound imager that can be inserted in a catheter for scanning artery walls.

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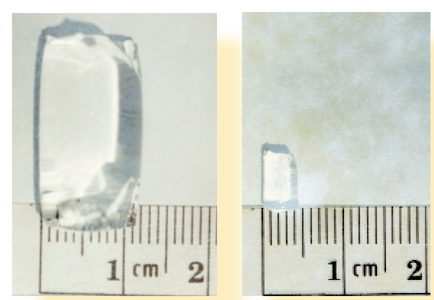
Artificial Muscles for Robots

Visible Light-Activated Polymeric Actuators (V-LAPA)



pH5.0 **pH4.5**

Light-activated polymer contraction by changing pH from 5.0 to 4.5

Project Summary

Next-generation robots will be micro and nano scale, requiring new actuators to perform the micro-manipulation. Material science has developed active polymers that contract and relax in a biomimetic fashion similar to human muscle. Barriers to practical application are that the polymers are activated by pH changes, usually requiring acidic and alkali solutions for activation/relaxation.

Polymeric actuators can emulate the peak powers of mammalian muscle (50-200 W/kg). Rapid, fully reversible, controllable means of activating these "artificial muscles" are highly desirable for telepresence surgery. Visible light can change the pH of a solution instantaneously and sustain the resulting pH change long enough for a polymer to contract or expand (milliseconds). A macroscopic pH change is accomplished by the presence of "jump molecules" located immediately adjacent to the polymer backbone. This in-situ pH change eliminates the slow, rate-limiting diffusion of hydrogen ions to the active site. The contraction/expansion of the polymeric muscle is determined solely by the intrinsic motion of the polymer backbone. The jump molecules chosen have millisecond lifetimes at room temperature and sustain millisecond pH changes. Above is a gel whose volume changes 24-fold on changing the pH a half unit. Applications include light-induced antiviral activity, microactuators, and remotely activated optical switches and pumps (especially where non-metallic, non-magnetic parts are required).

Technology Transfer

Funding of continued research is through Office Naval Research.

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LSTAT

Life Support for Trauma and Transport

Figure 3
Patient isolation aumentation to LSTAT

T in use during surger

Figure 1
Field grade LSTAT

Project Summary
As systems integrator, Northrop Grumman Corporation, along with the LSTAT team medical device suppliers, investigated the integration of the applicable technologies and conducted the engineering feasibility studies associated with a self-contained casualty evacuation platform that would bring to the site of injury the equivalent patient monitoring and diagnostic power and care treatment protocols of an Advanced Trauma Unit or Medical Intensive Care Unit in a highly compact and mobile design (Figure 1) that is compatible with air and ground evacuation vehicles. The design intent of the LSTAT was to provide advanced continuous medical care from site of injury through definitive care (Figure 2) using embedded state-of-the-art commercial off-the-shelf medical devices, data processing and management, open-ended architectures, and networked medical data communication schemes.

The LSTAT design consists of a suite of sophisticated electrical and mechanical devices such as physiological monitor, suction, defibrillator, blood chemistry analysis, 3-channel fluid and drug infusion pumps, ventilator, oxygen system, power system, and on-board computer system, fitted beneath a standard NATO casualty stretcher. With the “isolation canopy” system in place (Figure 3), the LSTAT acts as an environmentally protective (patient isolation and reverse patient isolation) and temperature-controlled medical treatment station suitable for CBW/HAZMAT "hot zone" casualty evacuation, protective transport to clean definitive care sites and "casualty overflow accommodation" for improvised (schools, parking lots, shopping malls, etc.) mass casualty medical centers.

With the Cooperative Agreement beginning mid-year 1994, Northrop Grumman researched the portable intensive care unit concept and its associated constraints, proposed engineering design approaches, and developed proof of concept articles, incorporated design enhancements, embedded advanced medical device functionality, performed test validations against rigorous military specifications and regulatory compliance standards leading to the current LSTAT Model 9602 configuration which received FDA clearance in June 1998.

Technology Transfer
Development and production of LSTAT systems continues under Army funding. Commercialization is through a spin-out company, Integrated Medical Systems, Inc.,from Northrop Grumman Corporation.

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Tactical Audio

Tactical Audio for Surgical Navigation

Project Summary

Modern surgical instruments and image guided surgery require support from advanced technologies. Sound (i.e., auditory and musical perception) is not used at all in modern surgery. CASI's new technology expands the surgeon's situational awareness using novel sonification strategies in support of tactical placement tasks. Consider the difficulty surgeons face in manually performing surgery while at the same time visually perceiving navigational guidance from a surgical planning system(e.g. digitized information is not intuitively registered and integrated with the patient). CASI addresses the problems of ergonomics delivery of the navigational guidance to the ears and hands of the operator. We base our algorithms on inverting the musical performer's paradigm. A musician places their fingers precisely and accurately with the intent to produce sounds in "tune". We use elements of computer music and musical perception to enable the surgeon to place their instruments precisely and accurately by adjusting sound properties so that proper instrument placement sounds in tune.

The use of audio feedback as a partial or total replacement for certain visual navigational guidance systems in the operating room can overcome this limitation. The aural modality is a comparatively rich modality which is relatively unencumbered in the operating room. Furthermore, auditory perception is both parallel—capable of discriminating between multiple simultaneous sensoria—and omnidirectional (e.g. in hearing a sound, one is not obliged to aim one's ear directly at the sound source). We believe a properly designed and applied audio guidance system can transcend the limitation image-guided systems encounter, and can provide an intuitive and information-rich interface for the surgeon.

A prototype commercial system for positional guidance in real-time surgical instrument placement tasks will operate by translating spatial parameters of a surgical instrument or device (e.g. position or velocity) with respect to some coordinate system, into a set of audio feedback parameters along the coordinates of a generalized audio space. Placement errors corresponding to deviations of the surgical instrument trajectory from a pre-planned or optimal trajectory in computer memory will be transformed by our proposed system into a set of audio signals that will indicate to the surgeon whether correction is necessary. This system will have wide application in computer-assisted minimally invasive surgical procedures such as tumor stereotaxis. The system is continuing development.

Technology Transfer

We are currently developing a prototype tactical audio system as an extension to the Sofamor Danek Group's Stealth Station system for image-guided stereotactical neurosurgery.

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Lensless Microscope

Dual-Use Telemedicine Support System for Pathology Images

1 - Computer Tower
2 - Loudspeaker
3 - Touchscreen Monitor
4 - Microphone
5 - Lensless Scanner
6 - CCD Camera
7 - Microscope
8 - Power Supplies
9 - Motion Controller

Project Summary

With parallel work done under grant from U.S. Army Medical Research, Materiel Command and from Redstone Arsenal (Alabama), Kensal Corporation has developed a revolutionary tool for pathologists employing digital technology which eliminates the inherent limitations of traditional microscopy. "Lensless microscopy" enables a pathologist to capture and display the entire coverslip and view it on a high resolution monitor. This image, referred to as the "virtual slide", is the scout image. Areas of interest (AOI) can be readily identified and selected for viewing at higher magnification. Since the coordinates of each new magnification are automatically recorded, the pathologist can return to the precise location of any area of interest previously viewed. Because it is now in digital form, the entire coverslip can be archived as a case file and transmitted for remote consultations.

Utilizing current limited telepathology resources, consulting pathologists are forced to render a diagnosis from high-magnification images preselected by the referring pathologist. By transferring the virtual slide to remote Kensal workstation, the pathologist can select his-her own AOI to view at higher magnification and thus produce a truly independent second opinion. True telepathology now exists.

During the development of the telepathology system, a library of pathology cases containing the scan of the entire coverslip and several corresponding high magnification images has been created. This research and development has spawned another tool which is call *Virtual Microscopy.* It is a self-running multimedia CD-ROM used for viewing pathology cases generated by Kensal's telepathology system.

Technology Transfer

The telepathology system rapid-prototypes are being utilized in research at Walter Reed Army Medical Center and Armed Forces Institute of Pathology headed by LTC Ron Poropatich MD. The technology is poised for commercialization and available through customary intellectual property instruments.

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Unified Man-Machine Interface

Robotic Surgical Systems for Minimally Invasive Surgery

Project Summary

Computer Motion is creating a new world of possibilities in minimally invasive surgery with the ZEUS™ Robotic Surgical System. ZEUS allows surgeons to go beyond the limits of MIS enabling a new class of delicate procedures currently impossible to perform. As robotic technology becomes integrated into MIS procedures, ZEUS will help decrease patient pain and trauma, shorten convalescent periods and reduce healthcare costs. Using the ZEUS system, surgeons have greater dexterity and precision and a more natural and ergonomic feel of surgery. At the console, the surgeon controls the instrument handles and views the operative site on a monitor. With a computer interface, the surgical instruments replicate the surgeon's actions at the operative site in real time. ZEUS eliminates human hand tremor and allows the surgeon to scale his or her natural hand movements to micro-movements inside the body. These benefits will give rise to new procedures, including a closed-chest heart bypass surgery on a beating heart through incisions of only a few millimeters.

Technology Transfer

Computer Motion, Inc., was provided seed funding by DARPA which led to the world's first robotic surgical system (AESOP) approved by the FDA. Computer Motion, Inc., is now a successful commercial company with an expanding portfolio of products.

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Flexible Robotic Manipulator

Development of a Flexible Surgical Robotic Arm

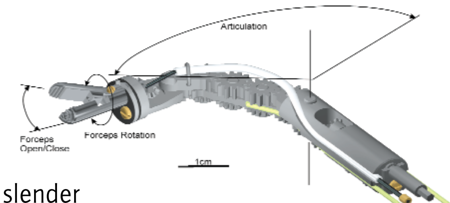

Figure 1

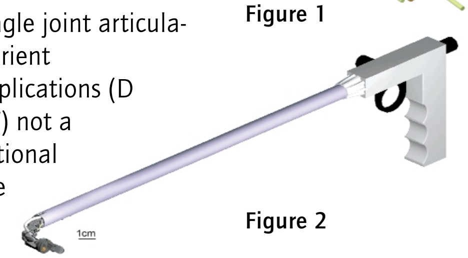

Figure 2

Project Summary

During minimally invasive surgical procedures, surgeons access surgical sites via slender instruments inserted through small ports. A few of these instruments provide single joint articulation up to 90 degrees, but this is insufficient for placing sutures with arbitrary orient advanced suturing capability, the Dexterous Articulated Linkage for Surgical Applications (D provides improved dexterity and reachability via three Degrees-of-Freedom (DOF) not a able in current instrumentation. As indicated in Figure 1, these DOF are bi-directional articulation (up to 180°), unlimited tip rotation, and end-effector actuation. The DALSA design has been thoroughly optimized to provide maximum workspace, both reachable and dexterous, load capacity, and durability with minimal backlash and improved repeatability. Manufactured from high-strength stainless steels, DALSA is designed to support 4.5N loads at the tip of a 1cm needle with infinite life and intermittent loads up to 8.7N

Application of the DALSA as an end effector of a robotic system will enable motion scaling, tremor filtering, simplify tip placement, and above all, facilitate and further telesurgical applications. The dexterity provided by the instrument will enable delicate tasks, such as suturing of vascular tissue for advanced procedures like the Minimally Invasive Coronary Artery Bypass Graft (MICABG).

Technology Transfer

The project has resulted in a functioning laboratory prototype and efforts are in progress to collaborate with instrument manufacturers and robotic systems developers.

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