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A ROBOT IN AN OPERATING ROOM: A BULL IN A CHINA SHOP?

J.M. Dolan, M.B. Friedman[1], M.L. Nagurka, and J.K. Gotow

Department of Mechanical Engineering and [1]The Robotics Institute
Carnegie Mellon University, Pittsburgh, PA 15213

Abstract

The essence of surgery is precise and coordinated motion by the surgeon and supporting staff so it is surprising that robotics - the technology of controlled motion - is not more widely used in the hospital operating room, especially since other technological innovations that increase patient safety and surgical productivity have been widely adopted. We are investigating interactive gestural and voice control of industrial robots as a means of enhancing surgical practice.

Introduction

The hospital Operating Room (OR) is a highly time-critical and capital-intensive environment designed to serve the needs of surgeon and patient. Since the essence of surgery is precise and coordinated motion by the surgeon and supporting staff, it is surprising that robotics - the technology of controlled motion - is not more widely used in the OR, especially since other technological innovations that increase patient safety and surgical productivity have been widely adopted. The benefits and ease of use of such innovations must, of course, outweigh the increased equipment complexity and failure rate which can accompany the introduction of new technology. Clearly, an OR overgrown with instruments and control panels is not desirable; an appropriate balance must be struck between levels of human effort and of technological support. Attention must be given to the design of safe and efficient human-machine interfaces. Without such controls, any technological innovation in the OR - particularly robotics - may come to be perceived as a menace, akin to the proverbial "bull in a china shop."

Perhaps just because robots are capable of self-initiated motion in an environment where all movements are "choreographed" to support the surgeon, they are rarely used in operating rooms. The only routine clinical application of a robot in the OR is the use of a PUMA 200 series robot to assist stereotaxic brain surgery at the Long Beach Memorial Medical Center (in Long Beach, California) [1]. In this robotic system, developed by Dr. Yik San Kwoh, a small industrial robot uses coordinates derived from "brain scans" to point a stereotaxic instrument guide toward the location of brain tumors inside a patient's skull. Prior to the commencement of neurosurgery, the robot and guide tube are locked firmly into position with external clamps. The chief advantages of the robotic system over conventional manual stereotaxic pointing systems is the ease and rapidity with which it can be repositioned and its reduced bulk.

In Dr. Kwoh's system, the robot is locked and clamped in its position prior to the surgeon operating on the patient. The increase in OR productivity is mainly pre-operative. There is minimal real-time communication between surgeon and robot. What are the interactive surgical tasks that can be enhanced by the use of current industrial robot technology? That is the question addressed by our research.

If the usual industrial robotic application paradigm were used, we would seek to enhance OR productivity by replacing some member of the OR team with a robot. An example might be the surgical nurse who passes instruments and supplies to the surgeon. The assumption would be that the nurse is merely dispensing items to the surgeon and receiving them back for storage upon command. However, this assumption would be false; OR staff - particularly the surgical assistants - exercise judgement in anticipating the surgeon's needs and monitoring patient safety. Although we might be able to replicate their movements, current technology would not permit us to initiate their anticipatory actions that are based on extensive experience and subtle sensory cues.

Instead, we have chosen to investigate robotics that can enhance a surgeon's productivity by performing services that are difficult for anyone to do for the surgeon. We seek to increase the efficiency of the surgeon and enhance capabilities with automation, rather than increasing OR productivity by replacing personnel.

We have sought tasks, such as instrument positioning and holding, that require sensing the surgeon's intentions as expressed by the surgeon's actions and voice. These tasks, which do not require artificial intelligence or sensing capabilities beyond current technology, range from holding instruments steady or stabilizing them relative to rhythmic body motions, to positioning and focusing a surgical microscope. With these robotic instrument augmentations both the physical exertion and duration of operative procedures may be reduced. This strategy represents a proper division of labor between man and machine in the OR and has the twin benefits of extending the range of the possible and reducing stress on medical personnel.

In instrument-holding types of tasks, the robot must be directed to a given position where it may then be required to track patient body motions. Similarly, in the surgical microscope application, the surgeon's head position and orientation may need to be continuously tracked. Conventional means of on-line instrument position control are cumbersome at best. An alternative is gestural control, which we have implemented using a magnetic sensor and microcomputer to mediate between human and robot. Thus, the robot can be "piloted" to a given position or orientation by appropriate hand or head motions. This, integrated with voice control, is a more intuitive instrument positioning method than those currently available and is well-suited to the OR environment.

A Robotic Surgical Microscope

Surgical microscopes are currently used in a significant fraction (about 20 percent) of surgical procedures. A typical stereoscopic operating room microscope may weigh 10 to 20 kg with its auxiliary equipment (secondary viewing tube, laser, camera, *etc*). In order to reduce stress on the surgeon, speed surgery, and convey timely visual information about the operating site, it is desirable to have a flexible and unobtrusive way of repositioning and refocusing the microscope. Current methods are unwieldy, requiring either manual readjustment, which slows surgery, or the use of voice control or foot pedals to command individual axis motions, which makes it difficult to attain complex orientations. Neither method allows the surgeon to easily perform such actions as scanning along a blood vessel or nerve while doing continuous repair, or rapidly pivoting about a fixed focus, say, to determine the full extent of a tumor.

The alternative which suggests itself in the context of this paper is to automatically record the location of the operative field, to continuously sense the surgeon's head position and orientation and to reposition the microscope accordingly. In this way, the robot extends the surgeon's capabilities by relieving him of tasks for which it is well-suited. We have implemented such a system using an ISOTRAK low-frequency magnetic sensor by Polhemus Navigation Sciences, Inc. to obtain head position, an IBM PC AT to perform calculations and act as a controller, and a Merlin six-DOF robot by American CIMFLEX to hold the microscope and track the sensed position. A high speed of communication between controller and robot is attainable through the use of dual-ported, shared memory instead of a serial port.

Determination of the appropriate microscope position is made by assigning Cartesian frames to points on the microscope and the user's head and performing the mappings necessary to move from one frame to the next. Each frame is represented by a homogeneous transform [2] containing both position and orientation information. The origin of the frame of ultimate interest is located midway between the microscope eyepieces in the plane formed by the upper surfaces of the eyepieces. Frames of secondary interest are associated with a point midway between the user's eyes, and with the magnetic sensor, which may be attached to the head in an arbitrary position. Once the sensor frame has been read, a series of mappings results in the microscope frame. The inverse kinematics are then solved for the robot joint angles, which are converted into encoder ticks and sent to the appropriate locations in the shared memory.

The current software provides for three basic modes of operation: 1) tracking, in which the microscope imitates head orientation at a desired fixed (presumably small) distance from the eyes as the surgeon scans an area; 2) pivoting, in which the microscope pivots about a fixed focus as the surgeon seeks different views of the operating site; and 3) Cartesian, which permits fine adjustments. The various modes are invoked under voice control to afford the surgeon maximum freedom of motion.

The repeatability of the sensor and robot are less than the depth of field of the microscope, so that focus is well-maintained. We have been able to steadily improve the response from an essentially point-to-point mode using serial communication to a smooth, nearly instantaneous mode using shared memory, in which the computational burden has been entirely taken over by the IBM PC AT.

Other Instrument Holding Tasks

Temporarily or steadily stabilizing clamps, retractors, endoscopic and percutaneous instrumentation, as well as fluid infusion or suction equipment, are tasks that are occasionally performed by the surgeon, but usually relegated to surgical assistants. Holding position at a constant force is a mindless activity at which people are relatively poor. Performed by the surgeon, it is often a tiring and distracting task; performed by surgical assistants there is an additional problem of exactly communicating the position and force that the surgeon wants maintained. We can use the same basic technology described above for sensing surgeons' head position to sense manually indicated positions. We are currently investigating means by which the surgeon can control the robot's compliance by demonstrating forces directly to the robot and recalling previously taught force parameters by voice.

Conclusions

The project described in this paper is in the pre-clinical research phase to demonstrate technical feasibility. Prior to clinical application, we must demonstrate that the system is reliable, effective and safe. Of these precursors to OR use, safety dominates our current concerns. We have experimented with several commercial robots to serve as OR positioning devices. Our choice of the American CIMFLEX Merlin for prototype work was dominated by the safety issues. We currently have three levels of "safing" the robotic: software, braking, and counterbalancing. Within our supervisory software we ask the surgeon to confirm actions prior to critical robotic motions and we use a speaker-dependent voice recognition system. Exclusionary zones, into which the robot is forbidden to move, can be taught to the robot controller prior to commencement of an operation to minimize accidental interference with other OR equipment. In case of power failure or on emergency command, an automatic clutch-brake system prevents the robot from moving. Finally, if brakes fail, the main joints of the robot are counterbalanced to drift away from the operative field, toward the ceiling. Manual overrides allow the system to perform as a passive, counterbalanced microscope stand if active sensing fails.

In the near future we hope to move from system development, to pre-clinical trials with practicing surgeons. In our litigious society, the social and legal/financial/insurance aspects of interactive robotic assistance of surgeons in the OR may prove to be at least as complex and needing of resolution as are the technical aspects.

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