A Telerobotic System for Augmentation of Endoscopic Surgery

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Abstract

We have begun development of a telerobotic system to replace a human camera operator in endoscopic surgical procedures. The system will consist of a remote center-of-motion manipulator holding the endoscope; a computer workstation supporting image processing, graphics, manipulator control, and other functions; and a variety of man-machine interfaces (voice, instrumented joystick, etc.). A prototype system using an industrial robot has been implemented and used to demonstrate essential functions.

Introduction

Computer integrated surgical procedures (diagnosis, planning, execution, and followup) may be expected to increase dramatically in the coming decade, as present trends toward geometrically precise and minimally invasive surgery accelerate. A number of systems have been developed for various forms of "frameless" stereotactic neurosurgical procedures (e.g., [1], [2], [3]), orthopaedics (e.g., [4], [5]), craniofacial surgery ([6]), ENT (e.g., [7]) and other procedures.[1] One common characteristic of these systems is that they rely on intra-operative position sensing to *augment* a human surgeon's ability to accurately execute a surgical plan based on 3D medical images. A machine capability is coupled with human judgement to perform a task *better* than either could do alone.

Similarly, the number of endoscopic and other minimally invasive surgical procedures has grown explosively over the past few years.[2] Two salient characteristics of these procedures are that the surgeon cannot *directly* manipulate the patient's anatomy with his fingers and that he cannot *directly* observe what he is doing. Instead, he must rely on instruments that can be inserted through a trocar or through the working channel of an endoscope. Often, he must rely on an assistant to point the endoscopic camera while he performs the surgery. The awkwardness of this arrangement has led a number of researchers to develop robotic augmentation devices for endoscopic surgery (e.g., [10], [11], [12], [13]).

The key requirements of any telerobotic surgical aid are safety, responsiveness to the surgeon's desires, dexterity, and precision in executing the task. Furthermore, even early versions should offer real advantages to the human user while not requiring a fundamental

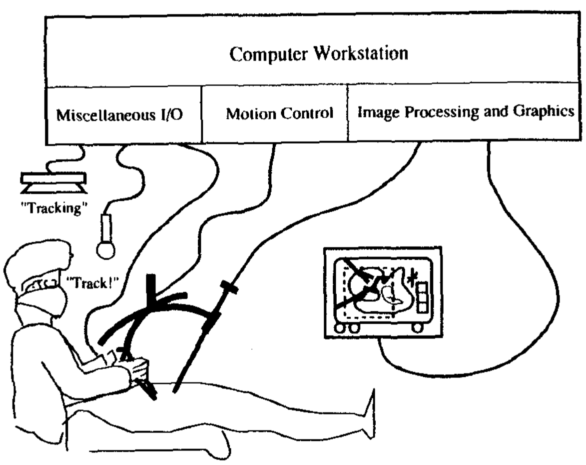

Figure 1. System Overview

[1] This list is not exhaustive. A fuller literature summary may be found in [8] or in some of the other papers cited.

[2] For example, about 20,000 laparoscopic cholecystectomies were performed in 1990; in 1993 the number is expected to be 600,000 [9].

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change in other aspects of the surgical procedure. Consequently, we have chosen to concentrate initially on the relatively simple task of pointing the endoscopic camera. Even this task is non-trivial for human operators, especially when angled or flexible endoscopes are used, and it is plausible to expect that a computer-controlled device can do *better* than the average assistant. A telerobotic system would reduce the number of people required around the operating table and could increase the surgeon's direct control over an important aspect of the procedure. Further, the experience gained will permit ready extension to more delicate tasks.

System Overview and Functions

The system architecture is illustrated in Figure 1. The endoscope will be manipulated by a remote center-of-motion robot positioned so that its center-of-motion coincides with the entry point of the endoscope into the patient's body. The camera will be interfaced to a frame grabber/image processing system on a computer workstation, which will also control the manipulator, and will support a number of other man-machine interfaces, such as computer voice recognition, synthesized speech, joystick-like devices mounted on the surgeon's instruments, and similar devices

The computer is capable of *visually tracking* the surgeon's instruments and computing their 3D position relative to the position of the camera. In the simplest use

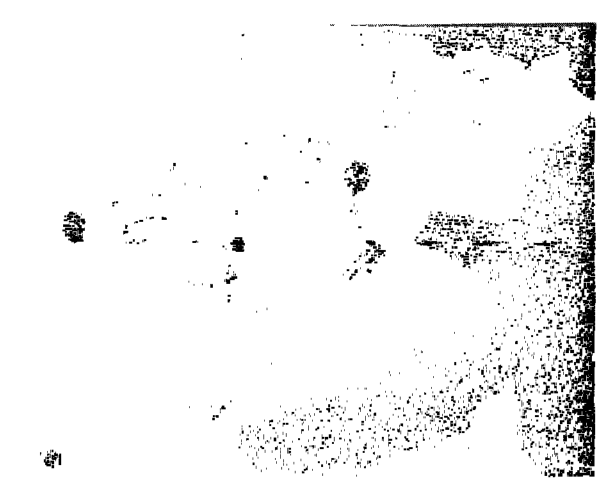

Figure 2. Remote Center-of-Motion Robot

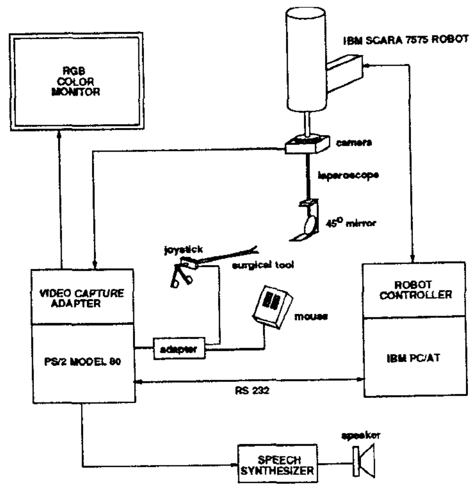

Figure 3. Experimental system.

of this facility, the surgeon can *point* to an anatomical feature and have the computer point the camera at it. Alternatively, the surgeon can use an instrument-mounted joystick to *teleoperate* the robot to position the camers or to position a cursor on the display screen to *designate* a feature. The computer can then aim the camera at a designated feature, can visually zero-in on a desired target, and can also visually servo to track the surgeon's instruments or anatomical features. Similarly, the surgeon can designate multiple points along a path, cause the manipulator to *zoom in* for a closer look, and then instruct the manipulator to slowly *traverse* the designated path while he concentrates his primary attention on the screen (e.g., to inspect along a blood vessel). Other functions include geometric *calibration* of the camera-lens system, *image archival and retrieval functions* for recording key scenes in surgery and recalling reference images, etc.

Prototype Implementation and Status

We are presently modifying a remote center-of-motion manipulator built earlier for craniofacial surgery [8] by adding motors and a suitable camera carrier. An operational system is expected by Fall 1992. In the mean time, we have constructed the simple 4 degree-of-freedom system shown in Figure 3, using an IBM 7576 robot, PS/2-based image processing system, and a surgical laparoscope with removable "periscope" optics. Except for image archival, we have used this system to demonstrate the basic functions described above for 0° and 90° viewing angles. We have also begun to experiment with stereo visualization and graphics and with the use of narrow-angle stereo to define 3D anatomical feature and instrument locations. The image processing system can follow instruments at about 9 Hz, which is adequate, although significant improvements can be made. Further, even a "novice" user can quickly learn to use the system well enough to easily position the camera where desired. Although considerable work remains to be done, this early experience is very encouraging.

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