ROBOTIC MANIPULATORS AND SURGICAL TOOLS: AN AID OR HINDERANCE

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Abstract. *Robotic manipulators and assist systems have been available to surgeons for some time now but are they performing as well as expected? This paper takes a look at what is expected of these devices, the surgeons view, and what is delivered, the researchers view. It is very easy to forget that as recently as only a few years ago surgeons and clinicians had to rely on X-rays as the only method of 'seeing' inside a patient. Tthe first MRI exam ever performed on a human was performed on July 3, 1977, an event took place that would forever alter the landscape of modern medicine. Outside the medical research community, this event made scarcely a ripple at first. It took almost five hours to produce one image. Examples of research projects will be given and some commercial products. The paper will bring some conclusions on the current state-of-the–art.*

Keywords*: robotic manipulators, surgical tools, medical devices*

1. Introduction

Robotic manipulators and assist systems have been available to surgeons for some time now but are they performing as well as expected? This paper takes a look at what is expected of these devices, the surgeons view, and what is delivered, the researchers view. Quite often these are not the same because there are two distinct schools of research into these types of devices. One school will spend a long time perfecting a mechanism or device and then go to surgeons and say to them 'We have built this lovely thing, can you use it for something?'. The other school will have regular contact with surgeons and be sensitive to their needs and listen to what they say to them and then develop what is required to solve a problem.

Surely this second approach is much better as it makes better use of scare resources and researchers. This is not to say that researchers should never design 'off-the-wall' but even those ideas should have a grounding in the solving of an acknowledged problem. It is this second philosophy that is followed by the people involved in the Medical Engineering Research Institute (MERIT) at Dundee and this has led to a number of very successful research projects, and also the creation of a 'spin-off' company to commercialize the results from this research.

2. Background to robotic manipulators

Robotic systems were first developed as programmable industrial manipulators. Pioneered by George Devol in the 1940's and 1950's as a point-to-point motion, magnetic process controller. Current uses are arc welding, complex assembly, ocean/space/ volcano exploration.

- 1938: Americans Willard Pollard and Harold Roselund design a programmable paint-spraying mechanism for the DeVilbiss Company.
- 1946: George Devol patents a general purpose playback device for controlling machines. The device uses a magnetic process recorder. In the same year the computer emerges for the first time. American scientists J. Presper Eckert and John Mauchly build the first large electronic computer called the Eniac at the University of Pennsylvania. A second computer, the first general-purpose digital computer, dubbed Whirlwind, solves its first problem at M.I.T.
- 1948: Norbert Wiener, a professor at M.I.T., publishes Cybernetics, a book which describes the concept of communications and control in electronic, mechanical, and biological systems.
- 1951: A teleoperator-equipped articulated arm is designed by Raymond Goertz for the Atomic Energy Commission.
- 1954: The first programmable robot is designed by George Devol, who coins the term Universal Automation. He later shortens this to Unimation, which becomes the name of the first robot company. 1959: Planet Corporation markets the first commercially available robot.
- 1960: Unimation is purchased by Condec Corporation and development of Unimate Robot Systems begins.American Machine and Foundry, later known as AMF Corporation, markets a robot, called the Versatran, designed by Harry Johnson and Veljko Milenkovic.

- 1962: General Motors installs the first industrial robot on a production line. The robot selected is a Unimate.
- 1964: Artificial intelligence research laboratories are opened at M.I.T., Stanford Research Institute (SRI), Stanford University, and the University of Edinburgh
- 1968: SRI builds and tests a mobile robot with vision capability, called Shakey.
- 1970: At Stanford University a robot arm is developed which becomes a standard for research projects. The arm is electrically powered and becomes known as the Stanford Arm.
- 1973: The first commercially available minicomputer-controlled industrial robot is developed by Richard Hohn for Cincinnati Milacron Corporation. The robot is called the T3, The Tomorrow Tool.
- 1974: Professor Scheinman, the developer of the Stanford Arm, forms Vicarm Inc. to market a version of the arm for industrial applications. The new arm is controlled by a minicomputer.
- 1976: Robot arms are used on Viking 1 and 2 space probes. Vicarm Inc. incorporates a microcomputer into the Vicarm design.
- 1977: ASEA, a European robot company, offers two sizes of electric powered industrial robots. Both robots use a microcomputer controller for programming and operation. In the same year Unimation purchases Vicarm Inc.
- 1978: The Puma (Programmable Universal Machine for Assembly) robot is developed by Unimation from Vicarm techniques and with support from General Motors.
- 1980: The robot industry starts its rapid growth, with a new robot or company entering the market every month.

When working robots can do many things faster than humans. Robots do not need to be paid, eat, drink, or go to the bathroom like people. They can do repetitive work that is absolutely boring to people and they will not stop, slow down, or fall to sleep like a human.

It is possible to identify three generations of surgical robot.

1. Pre-1980 - stationary mechanical arms with no intelligence. - Aesop®
2. 1980-1990 - some intelligence, environmental sensors with feedback control - Robodoc®
3. Post-1990 - mobile, autonomous, extensive intelligence.

The reality is that it is not so easy to produce surgical robotics as people often assume. There are many things to consider in the design aspects, and patient acceptability is paramount. There are many failed projects because the design team did not take all of the problems and user, both surgical team and patients, requirements into account.

3. Surgical Tools

These can be categorized into two distinct groups, hardware tools and software tools. Hardware tools can be classified as;

- Clamps
- Retractors
- Assist arms
- Individual surgical tools

Software tools can be classified as;

- Surgical planning
- Image guidance
- MRI
- CT

3.1. Surgical planning

It is very easy to forget that as recently as only a few years ago surgeons and clinicians had to rely on X-rays as the only method of ‘seeing’ inside a patient. Today ultrasound and advanced CT and MRI scans can now be used to create 3D images for a precise diagnosis.

In computer aided surgical planning a patient’s CT scan is loaded into a computer where a 3D reconstruction and arbitrary cuts provide enhanced visualization of the patient’s anatomy. Planning for each detail determines the type of result the surgeon will achieve. The models provide the surgeon with a high level of confidence before they ever perform a surgical procedure.

With current software it is possible generate virtual endoscopic images from 3D reconstructions or directly from CT and MRI data sets. Each method has advantages and disadvantages. Real endoscopy allows for biopsy of tissue for pathologic diagnosis, whereas virtual endoscopy allows the user to see through walls of vessels and organs in localizing lesions. Virtual endoscopy also allows the user to visualize organs as hollow structures which may aid in surgical planning. Applications of virtual endoscopy include viewing vascular structures, such as the aorta, gastrointestinal tract, cerebral ventricles and the tracheobronchial tree.

3.2 Magnetic Resonance Imaging

On July 3, 1977, an event took place that would forever alter the landscape of modern medicine. Outside the medical research community, this event made scarcely a ripple at first. This event was the first MRI exam ever performed on a human. It took almost five hours to produce one image. The images were, by today's standards, quite ugly. Dr. Raymond Damadian, a physician and scientist, along with colleagues Dr. Larry Minkoff and Dr. Michael Goldsmith, had laboured for seven long years to reach this point. They named their original machine "Indomitable" to capture the spirit of their struggle to do what many said could not be done.

This machine is now in the Smithsonian Institution.

As late as 1982, there were but a handful of MRI scanners in use. Today there are thousands and it is possible to image in seconds what used to take hours.

3.3 Image Guided Surgery

Image Guided Surgery (IGS) is similar to surgical planning except that it is used in real time during an actual operation and should be used in conjunction with the surgical planning stage to ensure a successful outcome to the surgical procedure. IGS technology combines traditional x-rays with computer technology, to enable surgeons to "see" precisely where on the anatomy they are operating during the procedure just as is done during the planning stage. The IGS system creates three-dimensional models of a patient's anatomy and shows them on a computer screen. It also shows virtual images of the surgical instruments that the surgeons are using.

The instruments have special LED markers fitted and are tracked by a positioning system installed in theatre, so that the computer software can generate the accurate placement of them. This combination is invaluable to a surgeon as they plan for a complex case, or when doing the case. Aided by the computer imagery, the surgeon can more safely navigate complex anatomy, and more accurately complete the procedure.

This technology is particularly helpful for accurately placing spinal instrumentation, performing decompression, removing tumours, etc.

When used correctly the key fact to remember is that the technology has a profound impact on ensuring better and safer surgical outcomes.

4. Some examples of research projects

A system was devised at Montréal using a CRS Plus A460 commercial six d-o-f robot arm with a remote centre of motion (RCM). Control is via an assistant who tele-operates the robot arm from a control box following instructions from the surgeon. It is large and cumbersome with "*some elbowing between the surgeon and the robotic arms*"

PADyC is a semi-active control strategy based on the premise that "*present major medical need is not concerned with fully autonomous robots*", which has been tested on a planar two d-o-f arm under laboratory conditions but has not been developed far enough for medical testing. Input to the system is via a PC and commands are entered via the keyboard.

In 1986 IBM's Thomas J. Watson Research Center and the University of California, Davis, began collaborative development of a system for Total Hip Arthroplasty (THA). This research eventually became the ROBODOC system released by Integrated Surgical Systems in 1992.

Probot (Imperial College UK) The world's first use of an active robot on a live patient in 1991. The 'robot' takes the form of a motorised ring with a diametral arch from which the cutter is suspended. With the addition of adjustable mechanical stops this arrangement guarantees a fixed remote centre of compliance which is arranged to be at a point in the prostrate gland.

The University of British Columbia developed a system intended to be used for microsurgical operations. It utilises a CRS A460 arm to hold the slave maglev wrist units. Two units are employed, one as an operating control (master) by the surgeon and the other as the slave unit attached to the robotic arm. The master is designed to be controlled by '*a tool similar to surgical instruments*' and the transport arm can be locked in place. The system is equipped with 10:1 position scaling and 40:1 force scaling

SARAH: Fulmer Systems Limited UK This is a neurosurgical robot that came out of the International Advanced Robotics Programme in 1988 through a DTI supported feasibility study. The manipulator consists of two discrete axis sets: a 2 degree of freedom mobility unit and a 6 degree of freedom precision arm with revolute articulation with a working envelope of a 300 mm diameter hemisphere and a payload of 5 kg. The whole assembly is wheel mounted, and can be manually moved to an approximate position near to the patient and braked.

Loughborough University UK - Orthopaedic robot This is a system is that is intended as a robotically deployed drilling platform for hip repair surgery. The platform has 5 d-o-f with the drill on a separate 6th axis. This final axis is coincident with the orthogonal axis of the standard orthopaedic drill which is held in an instrumented cradle. The system is floor mounted and locked in place by jacks onto the operating theatre floor.

IBM Thomas J Watson Labs An experimental 13 d-o-f robot for endoscopic surgery. It is a gantry type arm which is positioned above the patients abdomen. The method of control is teleoperation via controls on the instruments which interface to the video monitor indicating a point of interest and the control computer then moves the endoscope to the new position. An endoscope with a 2 d-o-f steerable distal tip is utilised.

PATH*finder* *(Armstrong Healthcare UK)* PATH*finder* is a precision neurosurgical system that allows surgeons to carry out deep-brain procedures with high accuracy. CT or MRI scans are used for pre-operative planning and the robot positions the toolholder at the entry point along a surgeon selected straight line trajectory. The surgeon prepares a burr hole and then the robot inserts the instrument. Clinical trials were due to start in 2002.

Acrobot (Imperial College UK) This is an active constraint robot being developed under a LINK initiative for total knee replacement surgery. It is “hands-on” in that the surgeon uses a force controlled input handle on the tip of the robot and the system allows the surgeon to move the cutter through bone but presents a large feedback force on the control handle if the surgeon attempts to move out of the pre-defined cutting region.

4.1 Research at Dundee

MERIT staff are currently working on a variety of projects, among them are minimal access surgery robotics, Orthopaedic surgeryrobots, colonic cancer inspection and treatment, throat biopsy systems, rehabilitation systems, robotic control interfaces, tissue engineering and surface coatings.

5. Conclusions

What can we conclude about the future of robotic-assisted surgery? Certainly as the cost of robotics decreases and production and competition increase, the use of robotic-assisted surgeries will become more affordable. This has the potential to decrease surgical complication rates and the hospital costs associated with them. Patients receiving the less invasive robotic-assisted surgeries are likely to have less pain and to therefore report higher satisfaction with their treatment, the hospital treating them, and their health plan. But are researchers really understanding their customers? Should not we as researchers be trying to make systems as small and unobtrusive as possible and adding useful functionality instead of just imitating, sometimes poorly, what clinicians are currently doing. What we should be doing is enabling the surgeon to carry out totally new procedures as well as enhancing what he is currently able to do.

6. Responsibility notice

The author is the only person responsible for the printed material included in this paper.