A Review on Surgical Robotic Systems: Limitations, Feasibility and Research

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Abstract— 1980's is considered to be the birth of surgical robots. Since then, many the research projects have led towards the development of robotic surgery. The present paper describes the concept of telesurgery in healthcare, the classification of medical robots and the future research directions in the field of surgical robotics. Commercially available robotic systems have their own advantages and drawbacks. The research articles aiming at development of robotic surgery have been reviewed

Key words: Robotic surgery, Medics, Surgical robots, tele surgery

I. INTRODUCTION

The technological advances in robotic surgery today, were once upon a time considered as a matter of science fiction. However, in recent times, this concept is getting very popular in US and Europe. The reason behind robotic surgeries getting more popular now a days is its immense need and the better advantages that it offers over non-robotic conventional surgeries. Minimally invasive surgery promisingly offers benefits like smaller incisions, less discomfort, low blood loss, lesser hospitalization, faster recovery and resuming to routine activities. Over and above this, the endo-wrist movement and 3D vision system overcomes the natural human limitations and provide better flexibility and dexterity during surgery. Thus, robotic surgery provides access to internal organs with high accuracy and precision thereby conducting complex procedures.

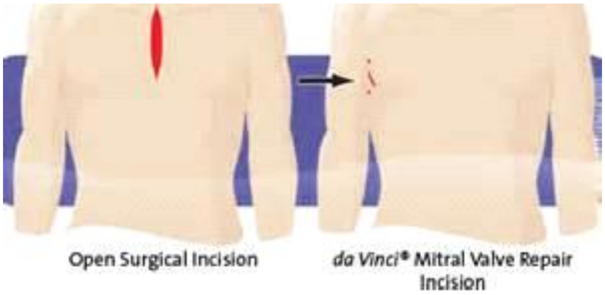

Fig. 1: Comparison of incisions in traditional and robotic surgeries [Intuitive Surgicals]

Although the concept of tele surgery originated in 1970s, till today it is noted to be in its infancy. Commercial surgical robots aim at providing the advantage of highly precise and sophisticated minimally invasive surgery with advance features like 3D HD camera with more than 10x resolution, 7DOF robotic arm more capable than that of humans along with tremor removal. Unfortunately this technology is very limitedly used in spite of being beneficial to the patients as well as surgeons. The reason behind is reluctance for adaptation to this technology because of certain drawbacks. According to a survey, there are presently 84 medical robots in various disciplines. Out of these, only 19 have been successfully tested on humans while 12have been granted license for commercial availability.

II. CONCEPT OF TELE SURGERY

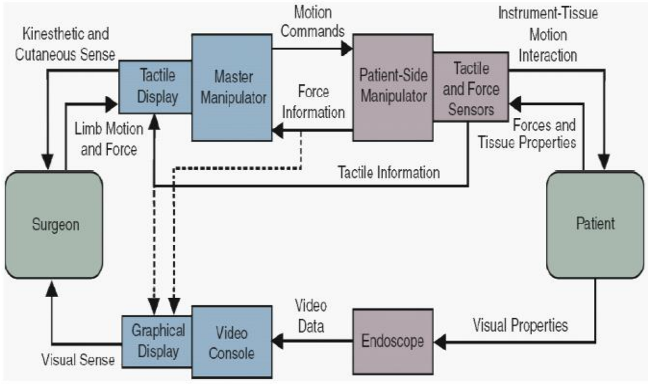

Fig. 2: Block diagram of telesurgery concept [Robot Surgery, Seung Hyuk Baik][16]

The basic concept of telesurgery aims at establishing a communication link between the master and slave units i.e the surgeon and the patient. The hand movements of the surgeon get transmitted through appropriate sensing and control system to the robotic arms or endoscope. On the other side, the tactile and force feedback are transmitted at the master unit along with a video display. Hence a two way communication takes place between the master and slave units to ensure suitable efficiency.

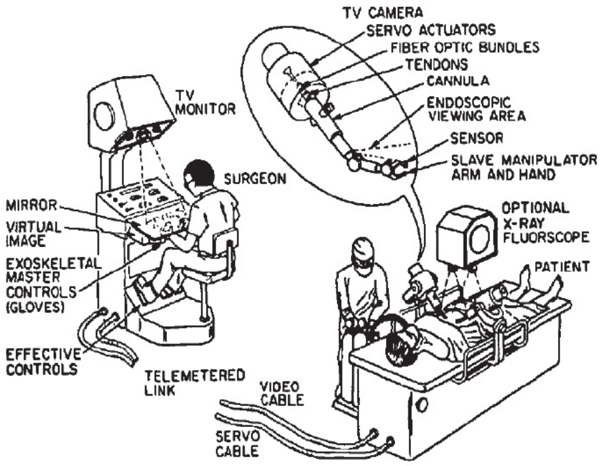

Fig. 3: Telesurgery concept [Image courtesy: NASA]

III. SCENARIO IN INDIA

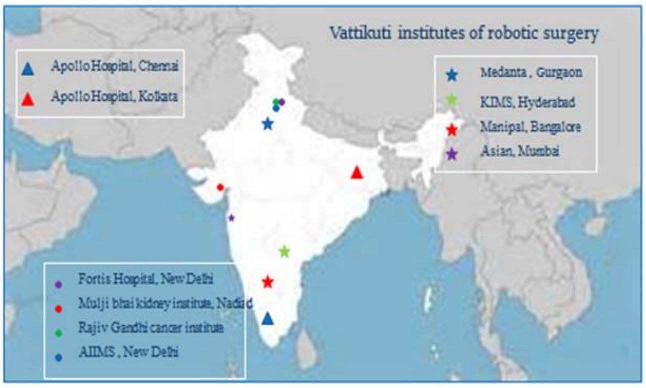

Fig. 4: Robotic surgery centres in India

India, with a population more than 1.25 crores, consists of only 10-13 centres capable of performing robotic surgery. In a developing country like India, expense is the factor which plays a major role in the acceptance of a new technology. Though the importance of robotic surgery is proven, many of the institutes refrain from adopting it because the installation and maintenance cost is unaffordable to most of them. Over and above this, the costly tools that enter the patient's body are not sterilizable and hence need to be disposed after the surgical intervention, which again adds to the cost. Ultimately, it is reflected in the patient's bill too. Size is another factor responsible for limited use of surgical robots in standard practice. As seen with commercially available robots, they are huge-sized bulky devices occupying majority part of the operating room. Third most important factor is complexity. Surgeons used to perform traditional surgeries, find it hard to adapt to new technologies. Initial training is mandatory before performing actual surgery, due to obvious reasons. However, this again imposes a problem since there are very limited robots and it seems hard to train all the surgeons with it. A possible solution to this situation is simulation training environment where surgeons receive adequate training and practice. This forms another research branch in the area of medical robots. Additionally, maintenance and sterility are another factors. Most of the surgical tools that enter the human body during the intervention, need to be sterilized for reuse. But due to inadequate techniques, these parts have to be thrown away, which is another issue of concern.

IV. MEDICAL ROBOTS

In the 1980s many research projects targeted robotic surgery, both remotely and locally controlled. It included underwater research, weightlessness effect and trans-continental surgical procedures. Presently, the number of surgical robotic devices is estimated to be around 5000 (all over the world). Robotic surgical devices come under a subgroup of medical robots and are distinct from rehabilitative robots and hospital-care devices. According to Medical Robotic 'Database', over 450 research projects on surgical robots have been carried out internationally, out of which not many could make it to practical applicability. International Standard Organization, ISO, has given the latest definition of robot as "Robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks."

Ancient surgeons, during early practices in around 390 B.C used to perform surgery with their naked hands. Later on, surgical gloves were introduced with the intention of reducing the risk of infection. Thereafter, with the innovation of surgical tools, the contact between the surgeon-patient was further reduced. The twenty first century has witnessed the practical and successful application of telesurgery where the patient is miles away from the surgeon. Thus, the surgeon has the capability of performing surgeries from any corner of the world. This innovation has led to an increasingly exhaustive research and development in this field. Commercially medical robotic devices have been in use since 90s, providing assistance to surgeons.

YEAR	INVENTION	BRIEF DESCRIPTION
1985	PUMA	Industrial robot adapted for CT-guided brain biopsy
1988	PROBOT	Ultrasound-guided system used to perform prostatic resections
1992	ROBODOC	Hip replacement milling device
1994	AESOP	Voice controlled Robot
1998	ZEUS	Computer Motion
2000	Da Vinci	Intuitive Surgicals

Table 1. Medical robots

Medical robots can be classified into the following two categories depending on the development concept.

- Systems based on Tele operation
- Systems based on Image-guidance

The first category of robots is remotely controlled by a surgeon. Intuitive surgical's Da vinci si is the best example of tele-operated surgical robot. Many neurological and orthopedic surgeries make use of image-guided robots, such as ROBODOC by Curexo. The major medical robots are enlisted in TABLE.1 .

A. Applications

Apart from commercial purposes, the applications of surgical robots may be extended for some crucial situations like remote treatment for soldiers during a war, medical support for long duration space missions or in case of spread of a contagious disease, thereby reducing the distance between the hospital and patient.

B. Advantages of Existing Technology

1) The most common argument in favour of robots is that they make the surgery minimally invasive.
2) Robotics makes surgeries extremely precise by eliminating hand tremors and movement scaling resulting is fewer errors.
3) Robots reduce the learning curve for laparoscopic surgery.
4) Robotic surgeries are ergonomically superior and cause less fatigue for surgeons in prolonged surgeries.
5) Shorter hospitalization, reduced pain and discomfort, faster recovery time and return to normal activities.

C. Limitations of Existing Technology

1) Cost: da Vinci system costs $ 1.4 million (Rs. 7 crores) and annual maintenance costs of $ 100,000 with a lifespan of five years.
2) The reduced surgery time in robotic surgery is more than offset by increased 'setup' and 'takedown' times for robots.

3) Bulky and space-occupying device
4) Reluctance to accept this technology (trust)
5) Highly technical ; less trained surgeons

D. Future Challenges

1) Tactile feedback
2) A safe, easy sterilizable, accurate, cheap and compact robot
3) Reliable telesurgical capabilities
4) Compatibility with available medical equipment and standardizing
5) Autonomous robot surgeons

V. RESEARCH IN SURGICAL ROBOTICS

A. Gesture Sensing Robotic Technique

N. Ahuja et. al designed a 3 DOF robot that was capable of reaching any object in the vicinity of 30cm and picking up any object weighing upto 0.5 kg. A general purpose robot had been designed using potentiometers as angle sensors, PIC microcontroller and DC motor. The position values were acquired through the sensors and fed into the controller where the voltage levels were converted into digital values using inbuilt ADC. Further, these values were compared with the default values present in the controller and essential PWM signals were generated for controlling the motor [1].

B. Varghese and B. Thilagavathi designed a hand glove for controlling an anthropomorphic robotic arm with 7 DOF. The sensing part consisted of a combination of potentiometers and accelerometers for sensing the human arm movement. 5 potentiometers, one for each finger, were attached to the glove using a string that acted like the tendons. The elbow and wrist motion were imitated using a 3 axis accelerometer. The transmission of the signals was carried out using an RF transmitter-receiver, which in turn was used to control the actuator consisting of DC motor and potentiometers for feedback i.e the servos assembly [2].

M. Ansari et. al had taken an initiative to patronize the robotic arm for hazardous situation people who could use their hand to move object within certain range to carry out that job. This work was meant to designing and developing of a microcontroller (ATmega) based robotic arm. The project deliverd a combined implementation of electrical, electronic as well as mechanical generation. The robotic arm responded to the gesture as well as could be programmed to go along a definite path and task. The system sensed the movement of user's arm and robotic arm replicated the given input gesture. The gesture was sensed by a number of potentiometers which were embedded onto a glove or other structural attachment. The movement in potentiometer determined the position for the servo motors driving the parts of the arm [3].

The design and implementation of a gesture controlled anthropomorphic robotic arm was proposed by G. Sen Gupta et. al. The robotic arm was designed in such a way that it consisted of four movable fingers, each with three linkages, an opposing thumb, a rotating wrist and an elbow. The robotic arm was made to mimic the human hand movements using a hand glove. The hand glove contained 5 linear slide potentiometers for controlling the finger movements and an accelerometer for the wrist and elbow movements. The actuators used for the robotic arm were servo motors. The finger movements were controlled using cables that acted like the tendons of human arm. The robotic arm was controlled from a distant location using a wireless module. A prototype of the robotic arm was constructed and tested for various hand movements [7].

Mamoru MITSUISHI et. al had undertaken the issue of adding force feedback capability to the surgical system. For this purpose, multi-axis force sensors were incorporated at the master manipulators which necessarily feedback the force sensed at the slave end. The unit consisted of 7 DOF (3 translational, 3 rotational, 1 grip) and cholecystectomy on a pig at a distance of 150 km was successfully performed. 3 ISDN lines were used for transmitting visual, auditory and control information with a time delay of 350 ms and 50 ms respectively for visual as well auditory and control. The slave manipulator consisted of three arms with the center arm holding an endoscope and the right and left arms equipped with radio knife or forceps. The total surgical environment information was transmitted and displayed on the large screen, which was divided into 4 frames to visualize abdominal image, vital signs like ECG, telemanipulator status and information of the assistant [8].

Javier E. Gonzalez applied the concept of remotely controlled surgery using wireless communication. A simple robotic arm with 2 DOF is chosen, to which surface EMG signals are fed from the user's arm [6].

Peter Berkelman and Ji Ma had undertaken the issue of developing a prototype surgical robot which is not only compact but also portable and sterilizable. The unit was light-weight enough so as to be placed on the patient's abdomen. Further advantages included its compatibility to be integrated into the operation theatre as well as easy portability to hazardous or remote environment. The researcher had targeted the major limitations of currently available medical robots i.e bulky size, long set up times, immobility and high expense. The proposed design also eliminated the need of an assistant to hold the endoscopic camera during the surgical procedure. Light weight ensured 1825 g and the diameter was no larger than 100 mm. Regarding the range, it incorporates a full 360 degrees of rotation and 10 degree inclination from horizantal upto fully vertical position. The robot neither requires any kinematics calculation nor any homing sequences. Aditionally, plastic draping was not required since the robot can be sterilized by autoclave repeatedly. Angular position feedback was provided through the sensors employing linear hall effect principle [11].

The aim of the researcher in this experiment was to examining remote surgery feasibility through the internet by comparing it to the effect caused different network data transmission. One limitation which the authors realized in the conventional surgical robot ZEUS was that the use of fiber optic lines made the surgery very costly. Using an ISDN, the surgery time was calculated to be equivalent to conventional cholecsystectomy procedure i.e. 90 minutes. UDP/IP network was chosen over TCP/IP for eliminating time delay in the control signal transmission (124.7 ms) [9].

VI. CONCLUSION

Robotic surgery promisingly offers better advances in comparison to traditional open surgery. The concept can be developed further by focussing the research and development in appropriate direction. Haptic feedback, tactile sensing, tele operation, portability, sterility and size reduction serve as future research directions in this area.

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