Technological Trends in Medical Robotics

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Abstract: Technology, in terms of medical robots, is entering in the field of medicine and is causing a disruptive effect in the field of therapy. Three million patients worldwide have gone through minimally invasive surgery by world's most popular *da Vinci* System. In this System, tiny instruments are inserted into patient's body. These instruments move as per the movements of surgeon's hands outside the body. Such robotic assistance reduces patient trauma and hospital stay as surgical outcomes are improved. From minimally invasive surgery, and hospital optimization to emergency response, targeted therapy, prosthetics, and home assistance, medical robotics happen to be one of the fastest growing sectors in the medical devices industry. Each section of the paper is devoted to a particular area of application of medical robots. The section ends with a discussion on limited research and future direction of the technology in that domain.

Key words: robots, medical, surgery

1. INTRODUCTION

Technology, in terms of medical robots, is entering in the field of medicine and is causing a disruptive effect in the field of therapy. Three million patients worldwide have gone through minimally invasive surgery by world's most popular *da Vinci* System. In this System, tiny instruments are inserted into patient's body. These instruments move as per the movements of surgeon's hands outside the body. For example laproscope which is an instrument consisting of a tiny camera in a thin tube and light at the end. The camera is used to send images to a video monitor which is kept in the operating room. This guides the doctors during surgery. The *da Vinci* System is used for many types of surgeries. Some of them are general, Cardiac, colorectal, gynecologic, urologic, head & neck and thoracic. (da-vinci-surgical-system, 2018) *Da Vinci System* is FDA (Food and Drug Administration) approved. Surgery is one area where impact of medical robots is greatest. The precise and accurate motion of tools has improved tissue manipulation and radiosurgery both. Use of robotic assistance reduces patient trauma and hospital stay as surgical outcomes are improved. (Beasley, 2012) From minimally invasive surgery, and hospital optimization to emergency response, targeted therapy, prosthetics, and home assistance, medical robotics happen to be one of the fastest growing sectors in the medical devices industry.

This paper summarizes the application of robots in various areas of health care. Comparison of human and robotic system has been made (section 2). At the end of each section, limited research and future direction of the field is discussed. Latest technological trends in robots being used in various domains of medical field are also discussed.

According to the "**Robot Institute of America**," 1979, "A **robot** is defined as a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks." This definition leaves out scope of everything immovable, tools such as scissors which can perform single task and nonprogrammable mechanisms such as manual laparoscopic tools. Though robotic systems are more costly, needs more space and also require extensive user training. But, robots are generally indicated where motions need to be quick and strong. They are used where untiring precise and accurate articulations are desired. Also where programmable motions are desired. Robots help to overcome technical limitations of stability, high precision and strong consistency in medical field.

2. HUMAN VERSUS ROBOTIC SYSTEMS

The visual and /or motor coordination among the various organs of a human surgeon are limited whereas they are highly accurate in a robotic system. The dexterity of a human surgeon is high within the limitations of his senses whereas robotic system possess high dexterity whose range exceeds the human perception. Though it is limited by number and type of sensors used in the system. (N. Nathoo, 2005) To take immediate decisions in case of an emergency, information integration and analysis is required. This capacity is high in case of a human surgeon whereas for a robotic system, it depends upon the Artificial Intelligence (AI) algorithm which is used to program the robotic system. (John E. Speich, 2004) The accuracy and scalability of a human surgeon is inherently limited as compared to a robotic system. As a function of time, stable performance of a robotic system degrades very slowly as compared with a human surgeon which degrades very fast. (S. Najarian, 2011)The adaptability of a human surgeon is high and specialty is generic whereas a robotic system is highly specialized though adaptability is limited by design. Both accept sterilization which is a must in an operation theatre. With Robotic system, there is another big advantage. It is unsusceptible to environmental hazards whereas a human surgeon is highly susceptible to radiations and infections. (T. Haidegger, June 2008)

3. ROBOTIC TECHNOLOGY IN MEDICINE

Today robots are used in many ways in a hospital such that in hospitals soon robot will be a regular member of staff. Presently their assistance can be categorized under following groups:

3.1 SURGICAL ASSISTANTS AND DIAGNOSTICS

The most fascinating use of medical robotics is in surgery. It has been predicted that the future operating room will be a sophisticated mix of virtual reality/ tele-presence workstations, stereo-imaging systems, microbots, robotic manipulators and computer integrated surgery. (Satava, 1997)

In performing a surgical task three entities are involved: the surgeon, the patient and the medium. The surgeon sees and through medium, interacts and communicates with the patient. There could be various configurations in this second entity called medium. In open surgery, the surgeon dissects the part which needs surgery and then using the standard tools, surgery is performed. A large open incision is made. The surgeon interacts with the internal tissues using direct hand contact or surgical instruments. Without any constraints on the surgical tool, he uses his own six DOF. He can manipulate the tool however he desires. So it is almost surgeon's expertise to conduct the surgery.

In Minimally Invasive Surgery (MIS), two small cavities/ ports are made in the patient's body. Through these ports, the endoscopic cameras and the tools are inserted into the body of the patient. MIS needs only four DOF as compared to the six DOF in open surgery. In MIS setup, apart from surgeon, who controls the endoscopic tools, one assistant is also required. The assistant manipulates and positions the camera. As per directions from the surgeon, the human assistant reposition the surgical tools with the endoscopic camera. However, the human assistant gets tired. For long time periods he has to hold the camera. The assistant in many cases these days is replaced by a 7-DOF robotic arm which is voice activated that repositions the endoscopic camera. Thus eliminating human assistance and can be called minimally invasive surgery with robotic assistance.

In industry, the tool path of the robot is predefined for most of the robotic tools. This principle is also used in medicine and such systems may be called semi – autonomous systems. Based on the requirement of surgical specialties (orthopedic, neurological, cardiac, etc.) and images captured by an imaging device, path of the robot can be defined. The robot, using position command, then executes the task without the intervention of the surgeon. Such systems are suitable for hard bones and tissues or also for soft tissues confined by bones such as brain.

In another robotic system, called guided system, the surgeon himself moves the tools in space. Precise and steady tool movements are provided by the surgical arms. The arm senses the forces and torques applied by the surgeon which are then converted into velocity command of the robot. The semi autonomous and guided system are reasonably priced. In medical robotics, most costly are teleoperated systems. A teleoperated surgical robot is like master/slave setup where one is surgeon console (master) and other the robot (slave). The surgeon console consists of voice command components with vision system and a set of handles. A robotic system interacts with the patient. This system has three robotic arms. Two of them are used to manipulate and control the surgical instruments and the third one to control the endoscopic camera. The surgeon positions the robotic arms by using two handles at the console. The surgeon controls the endoscopic camera arm voice commands. The view as seen by camera is shown to the surgeon console. Work is going on to mature the technology of force feedback. With this technology surgeon will be able to feel the forces generated by the interaction of surgical tools with the tissue. It uses position and force bilateral teleoperation mode. (A. Madhani, October 1998)

In place of stationary console, research is being done to develop hand held force magnifier instruments that detect small forces at the tip of tool. Also they can judge relative stiffness of the target. Advantage with hand held equipment is easy manipulation with variety of orientations and locations. (Yang, 2014). The pill sized in magnetically actuated soft capsule endoscope are being used for diagnosing diseases in gastrointestinal tract. They are being developed for use in diagnostic or therapeutic functions such as biopsy, drug delivery, in situ tissue property measurements and cauterization. A miniature mobile robot called HeartLander is used to perform minimally invasive therapy to the surface of the beating heart. The surgeon uses a joystick interface to control the device using a fiber optic videoscope displays with feedback to the physician. (Riviere N. A., 2004)

3.2 REHABILITATION ROBOTS

The robotic technology is extensively used as rehabilitation robotics. Variety of robotic devices help people recover from disabilities. This includs improved mobility, strength, coordination and quality of life. These robots can be programmed as per the need and requirement of each patient. The patients might be recovering from traumatic brain or spinal cord injuries. They can be also useful for neuromuscular diseases such as multiple sclerosis. Rehabilitation robots can further improve balance, walking, and other motor functions when integrated with virtual reality.

A large number of patients cannot perform everyday functions such as eating, drinking, washing, shaving, and teeth cleaning. Assistive robotic systems are used to assist individuals with such daily tasks. Handy 1 (Rehab Robotics Limited, UK), MANUS (Exact Dynamics, Netherlands), The Raptor (Applied Resources Corporation, U.S.A.) are few of them.

The elderly and people with impaired vision and lower limb function also need assistance. For them mobility aides such as wheelchairs and walkers are available. These are also equipped with intelligent navigation and control systems. Some of them are MAid (Mobility Aid for Elderly and Disabled People), SmartWalker, PHANToM.

When a limb is lost, a mechanical device called prosthetic is used to provide mobility or manipulation abilities. The Utah Arm 3 (Motion Control, Inc., U.S.A.) is an above-the-elbow prosthesis. In such devices electromyography (EMG) sensors are used. The response of a muscle **to nervous stimulation is measured by these sensors. Motion Control, Inc. manufactures variety** of other prosthetic devices. Prosthetic hand of artificial muscles is also available. It is made using shape memory alloys with five fingers and twenty DOF.

Research is also going on in the area of biodegradable electronics. Electrical stimulating electrodes are used to enhance bone regeneration. These generators can be connected to biodegradable radio frequency (RF) power generator thus not requiring surgical removal. (Mein Jin Tan, 2016,4) For enhanced and accelerated tissue healing, a manufacturing process is being developed to produce off-the-shelf bioactive plastics using donated blood plasma and platelets. (Erin P. Childers, 2016)

Exoskeletons are wearable robots that provides powered hip and knee motion. They are very useful for patients with spinal cord injury. It helps them stand upright, walk and climb stairs. The first exoskeleton to receive FDA clearance is ReWalk. It is being used for personal and rehabilitation use in the United States. Rehabilitation devices made up of soft material (whose Young's modulus is comparable to Young's modulus of human soft tissues, at the order of $10^4 \sim 10^9$ Pa) are being intensively researched (N. W. Barlett *et al* ,2017).

3.3 MEDICAL TELEPRESENCE ROBOTS

Robotic telepresence has been used for outsourcing of healthcare services. In rural of remote locations, physicians use robots for examining and treating patients giving them a “telepresence” in the room. These robots are remotely controlled with a head. The head supports a monitor and is equipped with sophisticated cameras with boom for closer physical examination and also have good navigation capabilities. (Yulun Wang, 2015) Intensive care unit, telerobots are used to increase access to off-site supervising specialists. (Mirna Becevic, 2015) Robots are designed specifically for elders. These telepresence robots support elderly in doing their daily activities independently. They also facilitate social interaction so as to overcome sense of social isolation. (Koceska, 2016). These robots have other applications too in rehabilitation and therapy, communication and monitoring and assistance.

3.4 MEDICAL TRANSPORTATION ROBOTS

These robots are deputed in the hospitals to deliver medicines, meals and other supplies to doctors, hospital staff members, and patients. This optimizes the communication inside the hospital. These robots are very high capabilities for self-navigation throughout the hospital.

3.5 SANITATION AND DISINFECTION ROBOTS

A study in the U.S. Centers for Disease Control, 2011, revealed that patients acquired 722,000 infections during treatment in health-care facilities in that year. Out of the above 75,000 patients died. In general, deadly infections caused by the antibiotic- resistant bacteria such as Ebola are on rise throughout the world. This paves the way for disinfection robots. Currently cleaning hospital is done manually. Disinfection robots are autonomous bots which use large ultraviolet lamps or hydrogen peroxide vapors to kill bacteria by disrupting their DNA. This prevents them to reproduce. Within minutes these bots disinfect a room of any viruses and bacteria.

3.6 ROBOTIC PRESCRIPTION DISPENSING SYSTEMS

The speed and accuracy are the biggest advantages of robots. Also speed and accuracy are the two features which are very important to pharmacies. Automated dispensing systems available in the market are highly advanced. These robots can now handle powder, liquids, and highly viscous materials ver easily.

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