ROBOTICS IN MEDICINE AND HEALTHCARE

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Abstract: *This seminar paper discusses the possibilities of using robots and automation in the field of medicine and healthcare. It contains brief historical overview, factors and challenges facing adoption and development of these technologies, as well as examples of robotic systems used in various medical procedures and areas.*

Keywords: *robot, machine, automation, medicine, surgery*

1 Introduction

With each passing year, the world is becoming more and more dependent on technology in almost every aspect. Because of this, technology is present in many areas and makes our daily lives easier and more convenient in various aspects. Many individuals, universities and companies are striving towards using these innovations in order to accelerate medical improvements, and thus increasing quality, efficiency and affordability of medical healthcare.

Medical robotic systems and equipment have now found their way into a broad range of specialty surgical applications, including urology, gynecology, cardiology, orthopedics, etc. Nowadays, various robotic systems and equipment are commonly deployed in procedures, such as gall-bladder removal, hysterectomies and prostatectomies. Their key feature is an ability to execute surgical procedures with extreme precision, thereby reducing the risk of surgical complications[1].

This seminar paper provides brief historical overview and shows some modern inventions and achievements in the field of robotics in medicine, whilst also discussing some potential factors facing adoption and development of these machines. As this is a very brought subject that can be discussed from many various angles and aspects, this paper focuses on some selected topics, as it would be impossible to cover every area regarding robots in the field medicine.

2 Brief history of robots in medicine

Early use of robots in surgery can be traced to the mid-1980s. Surgeons and engineers were trying to make advances in the field of neurosurgery and orthopedics, taking advantage of the rigidity of fixed bony landmarks to serve as points from which to guide early robotic tools[2].

2.1 PUMA 560

This was the first robot that operated on human patient in the year 1985 and performed neurosurgical biopsy. The accuracy that was achieved with PUMA led to its application in urological surgeries at Imperial College in London. This machine inspired other robotic designs, such as SARP (surgeon-assistant robot for prostatectomy) and PROBOT (prostate robot) machines[3].

2.2 Minerva

Stereotactical neurosurgical robot introduced in the early 1990s. It utilized an intraoperative CT (computed tomography) scanner and a head frame attached to the robot that allowed for increased rigidity and precision. Utilizing three-dimensional scans with fiducial markers to rigid points of the canium to determine position of the tip of a biopsy device[2].

2.3 Zeus and da Vinci Surgical System

First robots capable of reproducing the movements of the surgeon through manipulating robotic arms that are controlled via remote surgical console[2].

Zeus Robotic Surgical System was first used in a fallopian tube anastomosis at the Cleveland Clinic, Ohio, USA, in 1998. Later, it was used in gyneologic, urologic and hearth surgeries. It was the first robot that was used in transatlantic surgery[3].

Da Vinci Surgical System was first used in Germany in 1998 for robot-assisted hearth bypass. Later, it was used in the first ever reported robot-assisted radical prostatectomy in Paris, in 2000[2]. Currently The da Vinci systems are the most widespread robotic surgical systems[3].

(a) Surgeon Console

(b) Robotic Arms

Figure 1: ZEUS Robotic Surgical System[3]

3 Factors limiting adoption of robots in medicine

3.1 Safety

As medical robotic equipment is starting to be more and more widely used around the world it is crucial to make sure that these machines will work as intended. These robots have the ability to directly impact life and well-being of patients and therefore ensuring their ability to work as intended is very important. These machines need to work with extreme precision and even minor technical issues can result in conditions raging from extended post-surgical recovery periods to serious injury and even death. Also, public opinion and the way these robots are perceived is one of the key elements that can slow development and adoption of medical robots, as it is very important that public doesn't see these machines as something they should fear or resent[4][1].

In order to ensure global cooperation in development of medical hardware it is important to unify various requirements imposed by different nations around the world. The publication of IEC 80601-2-77 represents the culmination of efforts that began in October 2009. This standard tries to unify requirements across various fields and areas, such as definitions, general requirements, electrical and mechanical hazards. To this day various changes and modifications of this publication have been introduced by countries around the world[1].

3.1.1 Therac-25 accident

This was one of the most notable accident in modern history when medical machine malfunction led to serious injuries and death of patients. The Therac-25 was a computer-controlled radiation therapy machine produced by Atomic Energy of Canada Limited in 1982. Among various factors that led to this malfunction were bad mechanical design, lack of mechanical safety features, inadequate safety validation process by engineers and software bugs, just to name a few. This incident is to this day used as example case study for safety and ethics in medical hardware and machines[5].

3.2 Cost

In order to satisfy very strict safety and functional requirements these systems are very expensive. This is true when buying the machine and also while maintaining it, so that these robots can maintain their high degree of precision. Very hight costs associated with these robots also come from other areas, e.g., modifying hospital building layout in order to make space required for these robots or specialized trainings and courses for nurses and surgeons for use and maintenance of these machines. This also increases the time before these robots can be used effectively in practice[2].

4 Modern robotic medical systems and solutions

This chapter presents overview of selected use cases for robots in medicine and healthcare.

4.1 Robotic surgery training

Robotic surgical skills are unique from those used in either open or laparoscopic surgery. The acquisition of a basic robotic surgical skill set may be best accomplished in the simulation laboratory[6].

4.1.1 da Vinci Skills Simulator

This is one of the most commonly used commercially available robotic surgical platform. The prototype was first described in 2011, costs nearly $85,000, and includes 40 unique exercises. The simulator cannot function independently and requires a da Vinci Surgical System console[6][7].

4.1.2 RoSS - Robotic Surgery Simulator

The RoSS is a portable system that has been available since 2009. This system costs $100,000 and contains 52 unique exercises organized into five categories: orientation module, motor skills, basic surgical skills, intermediate surgical skills, and hands-on surgical training.

The most notable difference in hardware compared to the actual da Vinci Surgical System are the hand controllers, which have a smaller range of motion resulting in increased need for clutching[6].

Figure 2: The RoSS Robotic Surgery Simulator[6]

4.2 Precise Surgery With Image Guidance

The main goal of these robots is to precisely place a surgical tool in specific spots with high geometric accuracy. Images that serve as guiding data for the robot are obtained either before or during the procedure. Data that serves as guiding factor for these robots is often X-ray image, ultrasound or MRI (magnetic resonance imaging). E.g., X-ray system can enable the surgeon to avoid repeated exposure to radiation over the course of multiple procedures. Similarly, robotic manipulation of an ultrasound probe can help reduce the risk of repetitive stress injuries to the surgeon. One notable example that falls into this category is FUTURA platform that can be seen at Figure 3. It utilizes guidance by using high-intensity focused ultrasound.[8].

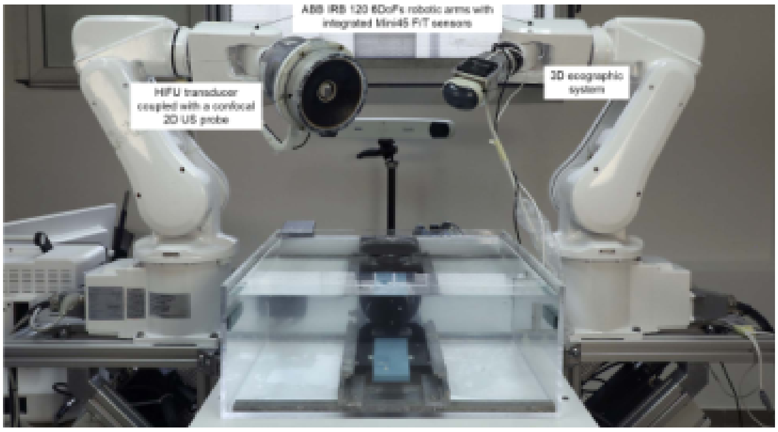


Figure 3: FUTURA platform for high-intensity focused ultrasound surgery[8]

4.3 Robots for Single-Port Access, Natural Orifice, and Transluminal Surgery

This category of medical robots has emerged in order to satisfy the need for minimally invasive deep interventions. These systems leverage progress made in the design of wire-actuated mechanisms, continuum robots, and catheter like systems to enable deep access in otherwise not so easily accessible places. Engineers are trying to achieve designs that are as small as possible while also maintaining high number of actuated joints in order to achieve complex shapes[8].

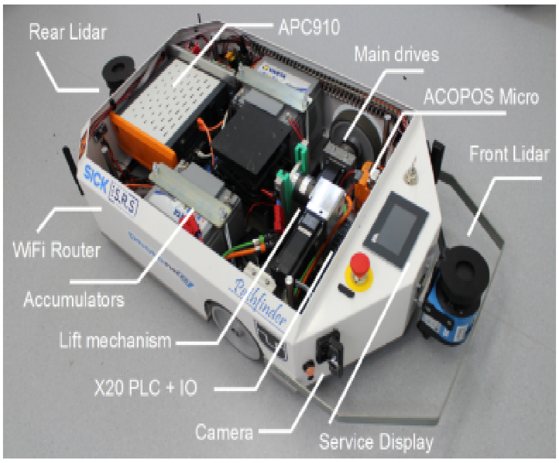
These robots present various engineering challenges in terms of resolution of kinematic redundancy and control, whilst at the same time requiring specialized designs, such as snake-like robots or multiarm foldable devices. One example of continuum robot can be seen on Figure 4. Another example of medical robots that fall into this category is SPRINT(Single-Port lapaRoscopy bimaNual roboT) robot developed by ARAKNES European Project[8].

Figure 4: Continuum robot used for natural orifice trans-urethral bladder access[8]

4.4 Robots for hospital logistics

Every day massive amounts of material of all kinds are transported around the hospital building. One emerging application for robots is hospital delivery. These machines can help reducing time which nurses, doctors and hospital staff spend each day carrying medical material as much as 30%[9]. Furthermore, the use of robotics for delivery can minimise the spread of disease, requiring less people to change locations in search of medical supplies[10].

The first mobile robot that was designed to deliver pharmacy supplies and patient records throughout the hospital building was HelpMate. This robot used sensor-based motion planning algorithms which addressed navigating in unknown and unstructured environments. Nowadays, many designs and approaches have emerged in this area. Notable examples include, e.g., Pathfinder (shown at Figure 5) from Slovak company Bačík or TUG from company Aethon[10][9].



(a) Mechanical overview

(b) Pathfinder in Košice Hospital

Figure 5: Pathfinder automated guided vehicle[11]

4.5 Spinal surgery

Because spinal surgery requires extreme precision and fine manipulation of vital structures, progress of medical robots for this use case has progressed slower in comparison to some other areas. However, since this type of surgical procedure requires accessing critical parts via limited surgical corridors and can require repetitive tasks over lengthy periods of time (which can prove problematic for humans) development of these robots has seen massive increase in development over the last few years, as they can provide necessary assistance to surgeons and therefore increasing precision and accuracy of such procedures[12].

In 2019 there were 7 robots in total that were approved by United States FDA - Mazor SpineAssist, Mazor Renaissance, Mazor XTM, Mazor XTM Stealth Edition, ROSA Spine, ROSA ONE Spine, and ExcelsiusGP-STM[13].

TiRobot from Chinese company Tinavi Medical Technologies is the first multi-disciplinary orthopedic robot created entirely in China. It has received approval from China FDA in 2016[14].

The da Vinci Surgical System has been successfully used in spinal surgery even though it's not approved by US FDA for spinal instrumentation (as it is telesurgical system instead of guide instrumentation)[13].

Figure 6: Mazor Stealth Platform with tracking camera, base station, bed and mounted robotic arm[14]

5 conclusion

This paper briefly discusses use of robots in the field of medicine. It offers short historical overview, discusses various factors that influence adoption and development of medical robots, as well as providing examples of these machines that are nowadays used for various surgical procedures and hospital-related tasks.

As medical robots are becoming increasingly popular it is also important to ensure that they will be safe for their intended operation and use case, as faults and malfunctions can harm and even result in deaths of patients. Cost of such machines and time needed to train the hospital staff to effectively use these robots also needs to be considered before adopting such solutions in practice.

The da Vinci Surgical System from an American corporation Intuitive Surgical is one of the most widely used and recognised robotic medical systems user worldwide, however, many companies are nowadays making medical robots and automation systems for various procedures, such as spinal surgery (discussed in chapter 4.3 of this paper), precise surgery (discussed in chapter 4.2 of this paper) or robots for single-port access (discussed in chapter 4.3 of this paper), to name a few. Many other robotic designs and machines can also be very useful for hospital staff, e.g., robots that help with tasks related to logistics and transportation (discussed in chapter 4.4 of this paper).

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