EPS UNIVERSIDAD FRANCISCO DE VITORIA

Fundamentals of Computer Engineering

Practical Work 1

MEDICAL ROBOTS

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Table of contents

Abstract

Since the dawn of robotics we have considered that they would one day do everything for us that we could imagine. In recent years, there have been some large milestones reached in the field of robotics related to healthcare, medical robotics. We have created machines capable of performing surgeries with equal or better precision than real surgeons, and tools to help us diagnose better, help patients recover faster, and save them time and hassle in the healthcare system. With the advancement of AI, this development of medical robotics will only continue to surge. However, there are ethical questions of data privacy and liability. This research paper delves into examples of medical robotics, the history of the topic, and where it will be in the future and its many potential uses.

1. Introduction

In 2024, an incredible surgery was performed on a patient with prostate cancer in Beijing, China. The medical team led by Dr Zhang Xu, who appears in figure 1, performed an incredible feat removing cancerous tissue from the patient's prostate. However, the lead surgeon who is the head of Urology at a hospital in China was not present at the surgery, yet somehow performed it. He was more than 8000 kilometres away in Rome. How was this possible? Through the use of an innovative procedure involving robotic arms that repeated the actions of the surgeon on another continent.

Figure 1

This story convinced us as a group to choose the theme of medical robotics. What Zhang Xu and his team accomplished would have been considered a miracle just a few years ago; it is an undeniably enormous step forward in the medical field. For a specialized surgeon to be able to perform their craft from anywhere in the world with the same precision, if not more, as if they were in the operating room themselves opens up many opportunities to help more people. We believe that one of the bases for human evolution is healthcare and we think that medical robotics is an area that will be responsible for achieving great advances in this field. A lot of questions came to us about this topic such as: How have these advances been made possible? What are the origins of these advances? What kinds of robots exist? Are they as good and promising as they seem? Are they worth being used currently or in the future? Are there still risks for the patients?

2. Robots overview

Main Concepts

Defining key concepts related to medical robotics is important before delving into the topic. An automaton is a machine that is created to copy human behaviour, and automatons have existed since ancient times. Automatons are the first manmade machines created for automating tasks. They help humans expend less energy for tasks they perform. Of course, they are very limited in that they can solely perform the task they were designed for. Throughout history, many automatons have been created, among which the following stand out for their complexity: “le canard digérateur” (Digesting duck), as seen in figure 2-1, was made by Jacques de Vaucanson in 1738 and “a Török” (The Turk), in figure 2-2, created by Wolfgang von Kempelen in 1770. The duck replicated the digestive process. The Turk was capable of playing high level chess and could perform the Knight’s Tour, which is a complex mathematical problem that requires the knight to travel to each part of the board while only touching the parts once.

Figure 2-1

Figure 2-2

Robotics is a key concept related to the topic in this research paper. However, one should not define robotics before defining robots. The word robot comes from Czech robota, which means “forced labour”. The first to use this word was Karel Čapek, a Czech author, in R.U.R (Rossum’s Universal Robots) in 1920. In this novel, the author defined the concept of man-made artificial beings created to perform repetitive tasks. Thanks to Karel Čapek this term became popular in order to describe any machine that could do human activities. Therefore, the definition of robots came to be: A programmable machine designed to perform tasks autonomously or semi-autonomously by interacting with its environment. In addition, robots are composed of mechanical components, sensors, and a control system that governs its behaviour.

Now we can move forward to robotics. The term robotics was utilized for the first time by Isaac Asimov, the science fiction writer. He introduced the concept of robotic in 1942. Because of this, Asimov formulated the Three Laws of Robotics in his novel “Runaround”, which states the necessary ethics principles to regulate the robot behaviour. These three laws are:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the order given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Thusly, robotics could be defined as the study or robot and the development of robots. Modern robotics started in 1954 when Unimate, the first industrial robot capable of performing repetitive tasks in manufacturing environments, was created. Unimate was used for the first time in 1961 when it was installed in a General Motors assembly line. From that moment, robotics has evolved a lot and it has been integrated into fields outside of manufacturing such as medicine, special exploration, personal assistance, and more. Moreover, AI developments have begun allowing us to advance robots to a next level, for example by letting us create autonomous systems capable of adapting and reacting to their environment, making decisions, without human intervention.

As just mentioned, AI is evolving robotics and, therefore, medical robotics and robots. So, it is necessary to define what AI is. AI is the simulation of human intelligence through machines, attempting to enable them to perform complex human tasks like reasoning, solving problems, and learning.

To comprehend this topic there is a final concept to be defined, automated planning. It is the process of using AI techniques to automate and optimize the allocation of resources and tasks over time. The main objective of automated planning is to achieve specific goals, reduce costs, and maximize productivity, thanks to the schedules and more optimized and efficient plans created by automated planning.

Control systems

It is necessary to introduce control systems and their basic components to have a full comprehension of medical robotics. A control system could be defined as a series of mechanisms with the objective to manage the proper and correct function of another system. Its action is based on three aspects: maintaining a constant value over time, comparing the real output of the system with the desired output, and finally, taking actions to reduce the error between the real output and the desired output.

There are two main types of control systems when they are being discussed, open and closed loop systems. These two are differentiated by the feedback they receive. Open-loop control systems do not use feedback, action is taking without being based upon a received output value. Closed-loop control systems use feedback to continuously readjust the corrective action necessary to maintain the desired output value.

On the other hand, control system components are:

- Sensors, which are responsible for measuring and constantly retrieving data of the process that is being controlled or of the environment. They are capable of detecting variables and have a vital importance in the system as a simple measuring error could affect the entire system.
- Actuators are responsible for realizing actions in response to controller's instructions. Therefore, they will perform some action in response to a control signal.
- Controllers receive the data of the process from the sensors. Also controllers have to make decisions in response to changes to maintain the system in its desired state.
- The plant is the main component, as it receives the control signals from actuators and give an output signal.

- Feedback systems assure the correct performance of the system following the desired objectives. They compare the real output value with the or desired output value.
- The User Interface provides a way for operators to interact with the control system.

Evolution of robots since their creation

The evolution and development of medical robots has been influenced by several key robots since the creation of the first robots during the 1950s-1960s. In the following paragraph we will give examples of early robots and highlight their contribution to the evolution of medical robots by means of their unique characteristics and advanced components:

- **Shakey the Robot:** Shakey Robot, developed at Stanford University in 1966, as you can see from the image 3-1, it was the first robot with the capability to use a form of reasoning to make decisions. This skill was made possible due to the application of the GPS [1](General Problem Solver) and the implementation of Automated Planning. Furthermore, its ability to make choices based on sensor data opened up possibilities for future medical robots that required use of data analysis and would base their responses and decisions off this data.
- **Stanford Arm:** This robot arm, also designed at Stanford University in 1969 as seen in image 3-2, was the first robotic arm to be operated through inputs from a computer. This demonstrated the potential future in robotic movements with more accuracy and precision by providing meticulous instructions that would be followed without flaw. Medical robots integrate technology comparable to this for tasks such as the surgery we mentioned previously, wherein precision is essential and could mean the difference between a successful or fatal patient outcome.
- **Cyberknife:** The Cyberknife was created by Accuray Inc in 2001, as seen in image 3-4, it was a system that combined robotics with radiation therapy to non-invasively target tumours with high precision. Furthermore, nowadays the Cyberknife is impacting the integration of robotics in healthcare systems to enable targeted interventions.
- **RISE Robotic Arm:** The RISE Robotic Arm was designed in Tokyo University in 2008. It used a form of Artificial Intelligence to have precise control and adjusted its movements based on feedback from sensors. In addition, this Artificial Intelligence component along with sensitive touch sensors, formed the basis for future medical robots used in surgery and rehabilitation.
- **Hinotori :** The Hinotori was developed by Medicaroid in 2020, as seen in image 3-3. It was designed for minimally invasive surgical procedures with components that guaranteed precise control, ergonomic use, and high-definition 3D visuals.

Figure 3-1

Figure 3-2

Figure 3-3

Figure 3-4

[1] An early artificial intelligence program designed to solve a wide range of problems

3. Types of medical robots

Remote-Controlled Surgery

Remote-Controlled Surgery, also known as telesurgery, is a type of surgery where a surgeon performs an operation from a different location than where the surgery is taking place through the use of robotic systems and advanced telecommunication technology. This type of surgery is possible because of the integration of robotic arms[2] equipped with surgical instruments such as precision scalpels[3], suturing devices[4], graspers[5] and clamps[6], and cauterizing[7] tools that allow exceptional accuracy and precision to be used for complex procedures. These instrument attachments on the robotic arms are controlled via a computer console that provides the surgeon with real-time visual information and a high-definition 3D view of the area in which the operation is being performed.

One main advantage that remote-controlled surgeries provide is that it enables surgeons to perform operations on patients who are located far away. This has a lot of prospective benefits for use in remote regions where specialized surgeons and expert doctors are not always readily available or cannot come to in a timely and convenient manner. However, these kinds of procedures require a stable and very fast internet connection, as a low latency connection between the robotic system and the surgeon's computer console is needed to ensure safety, accuracy, and effectiveness during the surgical procedure.

The technology behind remote-controlled surgery combines robotic tools with sensors and cameras, allowing surgeons to perform meticulous and complex movements, trying to mimic traditional surgery but increase the consistency of a good outcome and increase efficiency. Robotic arms add precision and eliminate elements like shaking of the arms or hands which can occur during surgery. Additionally, for these types of surgeries there are development phases for haptic feedback features which will provide surgeons the sensation of touching the tissue as if they were really performing the surgery by hand and in-person.

While remote-controlled surgery offers many benefits, it has also had many ongoing issues. There is a requirement for highly reliable technology because any interruption, glitch, or lag in the communication or operation of the devices can cause incredible harm to the patient and risk their life. Also, the cost of this equipment is not affordable for the places where it would be suited best, such as the remote locations which often struggle financially. There is also training required for the surgeons, technicians, and nurses who all would use this technology.

Despite these problems however, the constant evolution and development of robotics, Artificial Intelligence, and telecommunications ensures that in the future, remote-controlled surgery may more than likely become much more viable, common, and useful than it already is.

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[2] A robotic arm is a programmable mechanical device that mimics the functions of a human arm.
[3] A very sharp knife that is used for cutting through skin and flesh during an operation.
[4] Medical devices used to sew living tissues.
[5] A firm hols or grip.
[6] A device made of wood or metal that is used to hold two things together tightly.
[7] A medical technique that involves using heat or chemicals to burn or destroy tissue.

Minimally Invasive Surgery

Minimally Invasive Surgery is a surgery method designed to minimize trauma and to reduce the recovery time by using precise and small incisions wherein the surgery can perform, as opposed to the large cuts needed in traditional surgery. This type of surgery has many advantages such as reduced postoperative pain, faster recovery time, shorter hospital stays and care required for inpatient surgeries, less scarring, and lower risks of infections.

The minimally invasive surgery method involves advanced tools and techniques, such as laparoscopes, which are thin tubes equipped with a camera and a flash light that allows surgeons to view the inside of the body on a high-definition monitor. Instruments such as clamps or scissors are inserted through small incisions to perform the procedure. Computer-assisted robotic systems such as robotic arms have taken these types of surgeries a step further, in their ability to provide precision, absolutely stability, and a greater range of motion than an ordinary human hand of a surgeon. Normally, minimally invasive surgery is used in conjunction with Remote-Controlled Surgery, combining the benefits of robotic arms controlled by a console to perform the minimally invasive surgery under the supervision of an experienced surgeon who is displayed the surgery on the monitor.

Minimally invasive surgery also come with some problems and drawbacks. Just like telesurgery the surgeons need an advanced training in order to be able to perform this kind of operations. Also, not all patients are suitable for MIS, factors like medical condition and previous surgeries can affect in the viability of these kind of operations.

Minimally invasive surgery is continuously evolving too as our technology develops. AI and its advancement may be essential in the future for this kind of procedure, because it makes surgical planning simpler and the surgery more precise by providing and analysing real-time data, always with the aim of increasing the effectiveness and safety of the procedures.

Advancements in minimally invasive surgeries seem to be evolving towards a more personalized and less traumatic treatment in healthcare. This continued evolution will not only improve patient's experiences for a surgery but also their outcomes, and it paves the way for integrating more innovative technologies or concepts that help minimize invasiveness and risks even more, while speeding up recovery.

Surgery Without Human Intervention

These types of surgeries are a future concept of what medicine could one day be like, a potential outcome of where the scope of the medical field may be evolving. It is a difficult concept because in order to be able to apply this to the medical field we are in need of technologies much more advanced than what we currently possess. The use of robotics, Artificial Intelligence, and other automated tools are necessary in order to be able to have a surgery without human intervention. As the name suggests, it consists of surgeries and procedures being able to perform without the need of a human surgeon. Nowadays the extent to which this technology exists is only for basic tasks such as cutting and suturing tissue.

There are 2 main fields in which surgery without human intervention depends, and in order to consider this type of surgery as a viable option, much evolution and improvement is required in these fields.

Surgical Robots: One of the most advanced examples of surgical robots is the Da Vinci system, as you can see in figure 3, considered the peak of surgical robots currently. It uses telesurgery and can perform Minimally Invasive Surgeries as well. As seen in the photo, while the surgeon controls this robot with a console, it perform precise and controlled movements with specialized instruments by use of its arms. It is extremely accurate and therefore minimizes human error.

The newest version of the Da Vinci ´s systems is the Da Vinci 5. Released on March 15, 2024 it is equipped with advanced features such as Force Feedback technology (similar to the haptic feedback technology), used to give tactile feedback during surgery and greater precision with the controllers and vibration control. Its 3D imaging provides perfect surgical vision. Also, this version supports AI-driven insights for improved surgical outcomes and collaboration through integrated media tools.

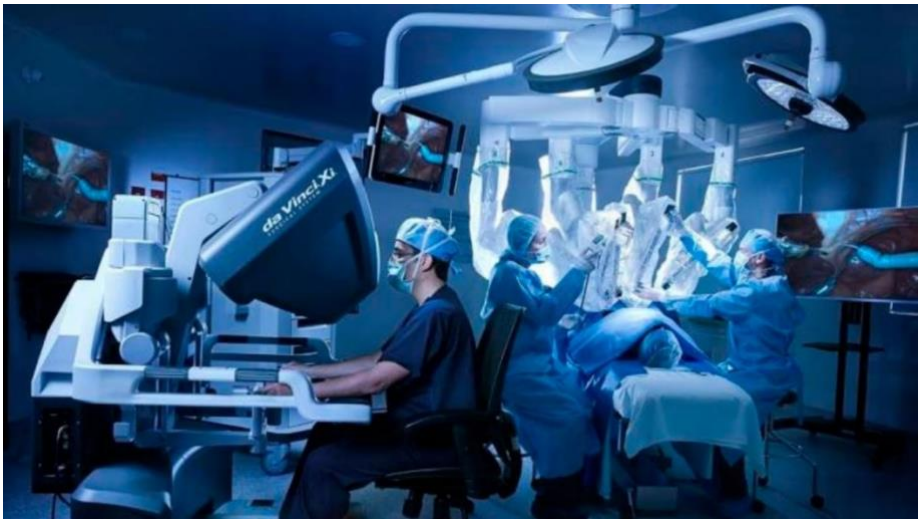

Figure 3

Artificial Intelligence: AI plays a key role in this kind of surgery. AI-based systems are needed in order to analyse large amounts of data, such as medical images. It should be able to detect abnormalities, provide accurate diagnostics, all of which helps in the planning and execution of the surgery in an autonomous way. Compared to traditional surgery, Artificial Intelligence should represent the surgeon's brain and knowledge. Also, it can be used to create a preoperative personalized plan dependent on the health and physical factors of the patient. In order to make this happen the AI would analyse patients' data and predict the best course of action, reducing human error and improving the outcomes.

4. Advantages and disadvantages

The three main fields in robotic surgery have their differences, as well as pros and cons. To compare these fields, we are going to look at them through different aspects.

One of the most important aspects for any type of robotic surgery is precision. The purpose of precision is that a mistake in surgery can mean a fatal or worsened outcome for the patient. This implies that precision is necessary to be reliable and secure or else the patient's health is more at risk.

Every robot has some basic requirements that we should observe in all of these 3 fields, to compare them and see if the drawback outweighs the benefits of this surgery or not.

Additionally, a huge problem of the mentioned surgeries which can be potentially performed by the fields of medical robotics that we mentioned in the future are the long lists of people that need to be operated on. The waiting times are as long as one year in some cases. These lists only increased after the Covid-19 epidemic. That is a big reason why we think these 3 fields of medical robotics can really help humanity and healthcare, by efficiently and consistently performing surgery and getting the people the help that they need in less time.

Aspects	**Telesurgery**	**MIS**	**Surgery Without Human Intervention**
Precision	The surgeons can be very precise thanks to the cameras and sensors of the robots, but this precision is limited by the connectivity between the robot and surgeon.	Robotic systems use in this type of surgical technique are created with the target of giving the best precision to the surgeons to do the smaller incisions and other aspects of the operation.	The precision depends on a program, instead of human abilities. So, an error in precision is impossible unless the program malfunctions or some factor is not accounted for that the program cannot handle.
Requisites	In telesurgery, as we said before you need an expert that can control robots in a precise way to make the operations, especially in places with bad access. As a result, these experts need more training than a normal modern surgeon, this implies we need a larger	With extra training, the surgeons can operate robotic systems that allow this type of surgical technique. However, you need a doctor in the place of the surgery, and it can only be used in some procedures.	While it doesn't need any surgeon to make the surgeries, this type of medical robot needs a complex infrastructure that costs a lot of resources, and complex programs.

	and more expensive training for the surgeons.		
Repeatability	The surgeons are people, so it's impossible for telesurgery to do operations for long periods without stopping at some moment. This fault comes from the need of rest that humans have.	In this surgical technique the robots are used to facilitate the work of the surgeon, but all the operations depend on the surgeon. So, as in telesurgery, the surgeon needs rest and cannot make surgeries for extended periods of time	The human factor in the surgeries is eliminated, so this type of robot can make a huge number of surgeries in a few days without any rest. However, this type of medical robots should be maintained regularly by experts to check for and avoid any errors that can affect its task.

5. Usage and potential evolution

Throughout the last decades, robots have been changing our way of life and work. Robots have been transforming many industries, especially the healthcare industry over the last three decades, and more specifically the field of surgery.

Robotic surgery with systems like “Da Vinci” for example, as we saw previously, allows us to perform less invasive and more precise procedures, making the recovery and healing process a lot easier for patients. All of these robots have been shown to improve both the precision of surgery and post-operation results.

But robots in medicine are not solely for the surgical field. Robotics has branched out into many other fields of healthcare such as rehabilitation, where patients received personalized therapies to help them recover much faster. For example, there is a robot called ROBERT, as seen in image 4, developed by a company called KUKA. KUKA is dedicated to helping patients with mobility problems to recover strength in their muscles after surgeries or other situations like car accidents by memorizing and mimicking the therapeutic movements made by the nursing staff. For example, raising a leg of a patient, which it is afterwards capable of executing completely autonomously exactly as it was done previously and with the possibility of repeating it as many times as desired or required.

Figure 4

If we set our sights on the future, to the combination of medical robots with new technologies like remote monitoring (which is the use of different devices in order to observe the recovery of a patient remotely), robotics is projected to be the key of the advance in this field. In addition, some robots and house sensors are improving the care of older people, like for example there is *Paro* which is a robot with the shape of a seal that is made to provide companionship for older people, reducing loneliness and improving mental health, being able to detect changes in the mood through interactions.

Now however the immediate objective in the field of medical robots, apart from making them more efficient and precise, will be to lower their cost (which is currently pretty high) and train people to become experts in handling these new technologies, as well as analyse the ethical aspects of the field to guarantee the patient’s safety.

6. Ethical analysis

An ethical analysis needs to me made regarding medical robotics. This analysis will include the most important topic: patient impact.

Medical robots will of course have an important impact on patients, as they are designed for them. Robots within medicine will allow, even more than now, an incredible improvement and development in the quality of life for patients around the world, even the ones that live in remote areas. A lot of disease will be cured as they will be diagnosed earlier, and the odds of survival and good patient outcomes will increase. Nonetheless, machines do not think as humans, they are not able to have ethical reflections and, therefore, some ethical issues arise.

Regarding privacy, the problem is the assurance that the personal data of the patients will be maintained and protected. With the incorporation of medical robots in the healthcare system, they will process a large amount of sensitive data. At first glance, this is not a problem as the machines are capable of processing an abysmal amount of data. Nevertheless, the issue arises when the data has to be stored, an essential process to improve the quality of the patient care. By storing the data, the machines have access to it and anyone able to control the machines has access to the sensitive data. This is where the real problem comes in because the data could be exposed or be extracted with malicious intentions.

Nonetheless, there are solutions that would allow us to ensure the data privacy of the patients. Security becomes essential in order to protect in that data in a right way, this can be achieved with the help of strong cybersecurity measures. Furthermore, it would be necessary to create and continue the development of existing rules and policies for preserving data privacy. Also, the constant human supervision of the machines is necessary to adapt them to those policies. These possible solutions would serve to control patient privacy and to ensure that the data is used only for medical purposes.

On the other hand, by bringing robots into the world of medicine, doctors no longer oversee and are responsible for all tests. Robots will carry out all tests and even provide help for diagnostics. So, doctors will control machines and will be responsible to check that the information they offer is right. This situation is idyllic if done right, as human errors would be incredibly decreased and quality of life would considerably increase. The issue appears when things do not go well. If a test goes wrong and the doctor chooses a bad diagnosis, whose fault is it? To be able to answer this question, protocols, instructions and rules must be made. Doctors need to know what to do in every situation and that they will be responsible for the situation if things go wrong. Then, doctors have to ensure that every robot is working in the right way to avoid legal or responsibility problems in case of error.

To summarize, medical robots are useful and provide a lot of advantages to the medical field and to patients. But with regards to ethical issues, robots must be controlled and supervised to preserve privacy and to avoid legal problems, among other reasons. This involves an extensive adaptation and education of doctors to be able to use and to work alongside robots correctly and an extensive software and hardware maintenance of the machines. These actions will take medicine with medical robots to new incredible heights of development, whose consequences will be gratefully accepted all over the world.

7.Conclusions

To sum up, we have learned and discovered that medical robots are likely to be the future of the healthcare field. The field is rapidly and constantly developing, and it is unsure but exciting where it is going to go with the recent advancement of Artificial Intelligence. This field has a lot of future projections as every new achievement in technology means a new possible achievement in medical field. Thanks to medical robots, the accuracy of tests is almost perfect, and the diagnoses are more accurate.

They may not be cheap, and it may take a long time for people to trust or prefer robotics to humans, but there are too many advantages to look over to not consider their integration into the healthcare field. In some years, news stories like the one that inspired this project, could be normal and commonplace procedures that are done every day. The main objective of medical robots is to achieve things that humans cannot get done, with better precision, faster, and more consistently. Perhaps thanks to them, everyone in the world would be able to receive the attention needed to their health, wherever they are, and whenever they need it.

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