APPLICATIONS OF ROBOTICS IN MEDICAL FIELD

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Abstract: *Commercial usage of robots dates back to the 1960s, when first robots were used for lifting and transporting of heavy objects. Since then, as the computer technology advanced and robots became more affordable, their presence expanded into different industries completing various tasks from stacking and sorting up to complex ones such as assembling or welding. In this paper, we will discuss impact of industrial automation in the field of medical environment and how it is changing the face of modern medicine.*

Keywords: *medical automation, medical robots, automated laboratory,.*

1 Introduction

In contrary to other industrial fields, first mention of robots in healthcare emerged in late 1980s, which means that automation took almost 30 years to expand into this sector. At that time, robots were mostly used for simple surgeries and minimally invasive surgery with the surgeon present in an operation hall, thus robot served only as an assistant tool. As already mentioned, first ever robot used in medicine was PUMA 560 in stereotaxic operation, in which PUMA inserted the needle into the patient's brain for biopsy. As the scepticism of the public, as well as of the patients themselves started to decrease and a technology advanced, applications of robots started to develop also outside of the operation hall. Nowadays, robots represent various roles in medical industry and are becoming a rising trend because of their high accuracy, low error and 24/7 service. The robots also find applications in areas where the conditions are life-threatening to medical staff, such as high infectious departments or radioactive environments. It is believed that using robots in the medical field can improve patient care and overall quality of service. In the future, as technology evolves, fully autonomous robots performing tasks of nurses or doctors can be reality. To better understand the direction of future development of robotics in medical field, we propose current situation in this field [1].

2 Classification of robots in medical industry

As there are no strict rules for how to classify the robots in medical industry, different classifications have been utilised across their history. One of the most commonly used classification, reflecting the ongoing trend, is based on their function and application field. In this case, the robots are classified into four main categories: surgical robots, rehabilitation robots, medical assistant robots and hospital service robots [2].

2.1 Surgical robots

The surgical robots, as their name suggests, are a group of medical robots used in surgery. Because of the fact, that they were the first robots used in medical field, their development is also the best in this field. It is estimated, that since their launch in 1985, surgery robots have been present in more than 6 million surgeries around the world [3]. Although they have been active for almost 40 years since their start, the public opinion is still very negative and their use is under supervision. Also their adaptation to operation halls is very slow all around the world except highly developed countries like USA, Japan, South Korea and more [4]. Surgery robots can be divided into two main categories: assisting robots and teleoperated robots.

Assisting surgery robots play a big role in laparoscopic approaches with main goals such as smaller incisions and reduced blood loss resulting in faster recovery of patients. Robot can serve as a support of surgeon, especially during orthopaedic surgeries, with perfectly still holding of instruments and implant components or can perform preplanned actions. There are also another aspects benefiting robot's properties such as good manoeuvrability and high precision, which can be put to good use mostly during challenging operations like single position fusions, which often require unergonomic setups for the surgeons. While all of the above-mentioned features mostly facilitate work of surgeons, the real utilization occurs during complex interventions. For example, during joint replacement surgery such as total hip arthroplasty, the surgeon needs to manually drill the cavity into femoral shaft for the implant. Because of the small tremors during the drilling phase, a small gap can be created between the implant and the bone which makes the fit imperfect. To fill in the gap between the implant and the bone, special type of cement is used. The breakdown of the cement from everyday wear can lead into a revision surgery in ten to twenty-five years, which is unpleasant for both the doctor and the patient. With the usage of the robot assistant, that can drill the cavity more precisely, a perfect fit can be achieved without the need of using the cement for fixing the implant, thus reducing the likelihood that the revision surgery will be required. Moreover, the procedure of drilling is less time-consuming, leading to faster surgeries with great consistency. The faster surgeries benefit not only the patient, but also the surgeon and whole hospital. At the moment, there are many robots in the field of assisted surgery. One of the most famous is a Mako robot by Stryker for the knee surgeries (fig. 1). Another mention is Rosa by Medtech specialising on brain surgeries [5].

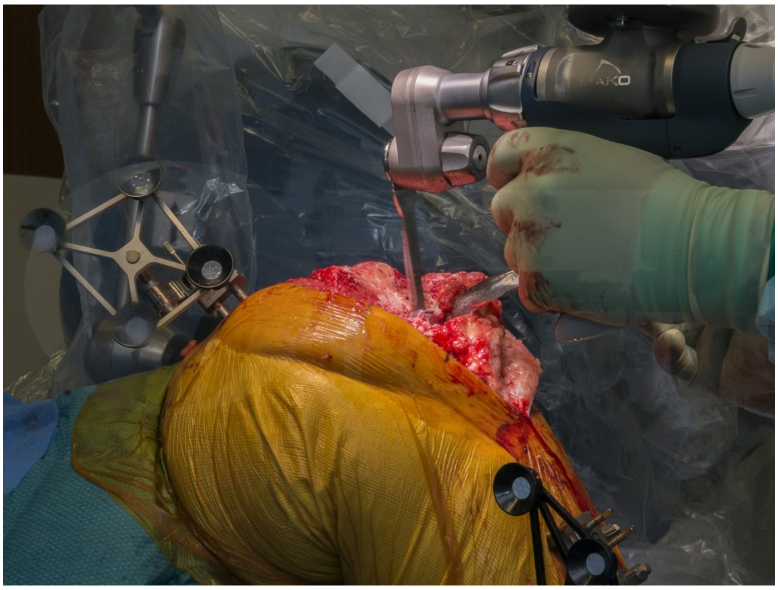

Figure 1: Knee replacement surgery assisted by Mako robot [6]

Teleoperated surgical robots are the second category of robots used for surgeries. Over the last decade, teleoperated surgical robots recorded by far the biggest development, that also unlocked their full potential. Their main principle is to enable surgeons the possibility of managing the operation remotely. The teleoperated systems are master-slave surgical robots consisting of two main parts, first is the workstation integrated into the surgical suite and the second part, which is a master console, where the surgeon controls the robot and his tools [7]. This concept was invented by Scott Fisher from NASA, originally designed to allow taking care of wounded soldiers on battlefield by surgeons far from a frontline, and later was adopted for the commercial use by different companies[8]. One of the most famous teleoperated systems are Da Vinci and Zeus. Both of these systems are very similar in their capabilities. They consist of three arms, from which two of them are designed for holding and operating the instruments and one camera arm with the binocular endoscope. Apart from this, moving cart with two cameras and light, providing 3 dimensional image for the surgeon is also present. The tool arms offer 7 degrees of freedom (DoF) and are controlled by pair of master control grips, while the position of camera and focus is controlled by pedals. Furthermore, the video system provides 10 to 15 times magnification with high resolution and true 3D vision. With the precision of 0,05 millimetres, the Da Vinci surgical system has now been approved for most of the general, as well as cardiac, gynaecological and urologic procedures by U.S Food and Drug Administration (FDA). These systems made a revolution by allowing surgical specialists operate patients all over the world from their homes, saving numerous lives [9].

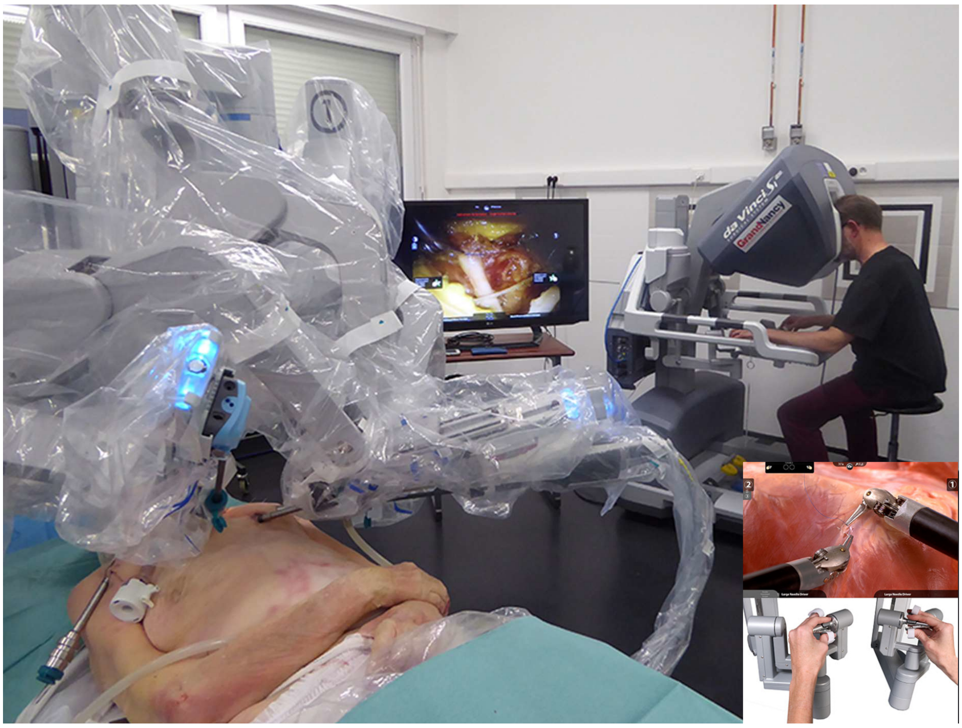

Figure 2: Da Vinci surgery system with the detailed view on the control grips [10]

It is also appropriate to mention special part in robotic surgery, which is radiosurgery. Even though it is called surgery, in radiosurgery, there is no need to use typical surgical tools like scalpel, scissors, clamps and needles. Instead of that, focused beam of radiation (mostly gamma radiation and X-rays) is used for treatment of cancerous tissues. In field of robotic radiosurgery, the CyberKnife system is well-known and most trusted system. It is fully autonomous system with the supervision of the operator. A target area is localised and reached through a combination of image registration algorithms and calibrated coordinate transformations. Treatment is mediated by large number of non-overlapping beams to respect the maximum dose of radiation of surrounding healthy tissues. This way, variety of tumours and cancers can be treated with minimal affection of non-cancerous tissues, pain free and with no invasion [11].

2.2 Rehabilitation robots

The rehabilitation robots refer to special devices, that play crucial role in a recovery of patients suffering from motor disability diseases such as stroke, multiple sclerosis, neuromuscular together with head and spinal cord injuries. They help patients to improve their strength, mobility, coordination, balance and other affected mobility functions. It is proven, that in comparison with the traditional physical therapy approaches, patients exercising with the help of rehabilitation robots achieve better results in less time [12]. These advantages emerge mainly from possibility of acquiring data during sessions, that can be quantified and can serve as a feedback to physiotherapist, who can then specifically adjust the rehabilitation process by better understanding the patients conditions and different intricacies. On top of that, rehabilitation robots can serve not only patients with disabilities but also elderly and disabled users in forms of intelligent wheelchairs and walking assistants. We can divide rehabilitation robots into two classes: exoskeletons and end-effector-based rehabilitation robots. Exoskeleton robots are designed as wearable devices focusing on the complete support of the upper or lower limbs. Their main function is to aid and assist patients in movement. These robots offer three different strategies: passive, active and challenging. In passive strategy, the robot itself performs movement and the patient is passive. Opposite to passive strategy, in active mode, the patient actively performs the movement and robot only acts as a support. In final phase of therapy, challenging strategy is used, in which robot acts opposite to the patient's movement, thus forcing the patient to develop the needed strength of muscles. In case of end-effector rehabilitation, these robots focus only on one joint instead of whole limbs. Nowadays, they are usually accompanied with virtual reality or at least visual interface. In these cases, the patient's goal is to, for example navigate the cursor on the screen into desired positions with highest possible accuracy and in limited time, thus acquiring fine motor skills [13].

Figure 3: lower limb rehabilitation with exoskeleton (left) and end-effector rehabilitation after stroke (right) [14, 15]

2.3 Medical assistant robots

The medical assistant robots are defined as robots, whose main service objects are patients. In general, robots that can not be assigned to either of the early mentioned groups and come into contact with patients falls into this category. They experienced sudden success during the recent outbreak of COVID-19, when hospitals recognized significance of these robots. Their main advantage is in reducing a face-to-face contact of medical staff with the infected patients, therefore, protecting health of the medical staff which is crucial for a proper functioning of the hospital. To reduce contact of physicians with the patients, the diagnostic robots started to be abundantly deployed. These robots can gather data about the patient's health, suggesting the possible diseases or post-surgery complications. Moreover, the doctor can remotely control the robot with all his tools such as electronic stethoscope, infrared thermometer and more [16]. Another application are capsule diagnosis robots, which greatly revolutionize the diagnostic and treatment of the digestive diseases. The first ever used capsule robot was a capsule-sized endoscope developed to capture images of the gastrointestinal tract. Nowadays, more features are added to the capsule robots such as *in vivo* body temperature detection and pH monitoring. After ingestion, these capsules can last for up to 16 hours of capturing 1 frame per second in the resolution of 480p and at the end of their life cycle, they simply leave the body in a natural way. When in stomach and intestines, their location is controlled by a magnet placed on the skin of patient by an operator, who can see the pictures taken by the capsule on the operator console. This process can be likened to sonography but instead of ultrasound conveying the image, in this case, it is the capsule robot with endoscope taking the pictures inside the patient [17]. By far the most famous robots in capsule robotics are the NaviCam by AnX Robotica and PillCam by Medtronic. Apart from robots for medical staff, there are also another robots, which are mainly designed to assist nurses and other hospital staff. One of these robots are social bots, which provide guidance and interaction with the patients. Main role of these robots is to navigate patients to the toilet or meeting room as well as to guide visitors around the hospital, which markedly relieve the nurses as they can focus on more important tasks. The future goal is to expand these robots into the retirement homes, where they could provide entertainment and social interaction for all residents, which can help prevent mental health problems. We also should not forget to mention that recently in Mexico, robot named Roomiebot started operating in hospital to triage COVID-19 patients. When patients arrive at the hospital, Roomiebot measures their temperature, as well as blood oxygen level and check patients medical records to identify Covid positive patients, who are then sent to the special department.

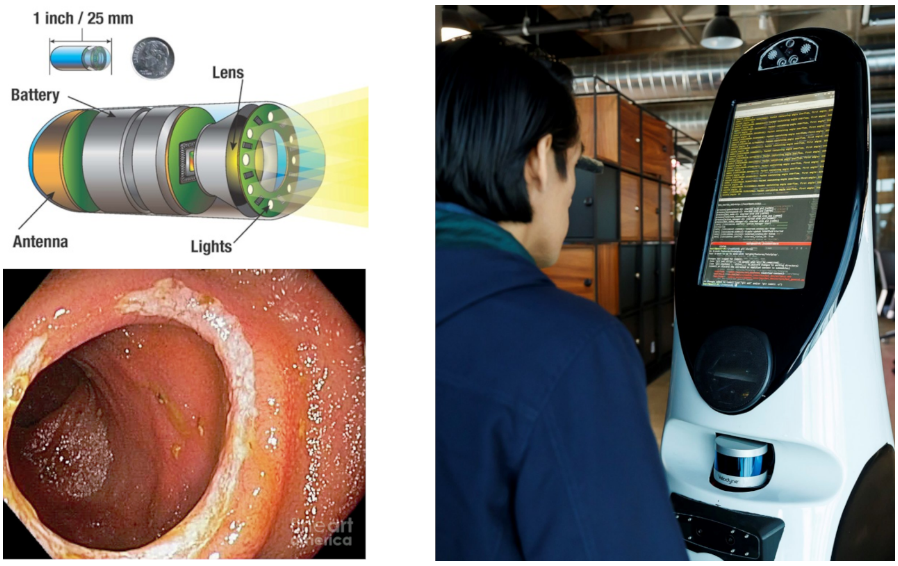

Figure 4: Capsule robot with a captured image of a small intestine affected by Crohn's disease (left) and Roomiebot with patient (right) [18]

2.4 Hospital service robots

Similar to the medical assistant robots, hospital service robots are robotic devices, whose main goal is to enhance the quality of services provided in hospitals and bear a part of tasks of the hospital staff. To differentiate them from the medical assistant robots, they do not come directlz into contact with the patients, meaning that their duties are connected more to the maintaining of the rooms and helping with logistics [2]. Throughout the Covid-19 pandemic, development of many robots specified for different tasks has started, but there have been some already deployed. One of the most remarkable robots already deployed is Akara. Akara is used for automated disinfection of the rooms and air replenishment. It consists of several UV lamps and air filters with fans on the two wheeled motorised base. Nurses can request the cleaning of specific rooms through mobile app and the robot can clean the room in less than 15 minutes with higher precision than manual cleaning could reach. This leads to better safety of patients from viruses and other health threats along with less pressure put on hospital staff that is responsible for manual cleaning [19]. Another hospital service robot, that is focused on deliveries, is TUG robot. As already said, this robot is used for transport of a medical material, right now, he is used for transport of bed sheets and food, but as his creators are working on a secured version, it is probable that in the future, it will be capable of transporting medication or samples intended for medical laboratories [20].

Figure 5: Akara disinfection robot (left) and TUG trnasporting robot (right) [21]

3 Conclusion

In this paper, we introduced brief overview of robots used in medical field. As the robotics in medicine is quickly developing, partially due to the Covid-19 pandemic, and more and more applications are being introduced, this paper was not intended to include all of the applications, but rather point out the most promising groups with the real applications already used in this field.

As paper suggests, there are numerous benefits in utilizing robots in various parts of the hospital ecosystem. For example, in traditional surgeries, robots can offer higher precision and shorter operation times, which enables new possibilities for the minimally invasive surgeries. Furthermore, their application can also unlock new approaches such as telesurgery or robotic capsule endoscopy. Outside of the operation hall, they can either serve for patients, like social bot or Roomie bot, offering interaction, guidance and other features, or they can perform routine tasks like disinfection or logistics with all-day service.

On the other hand, there are also significant drawbacks, that need to be solved, before the mass deployment of robots in medicine can happen. It is first and foremost a price, that halts the expansion. A purchase price combined with the high operation cost cause, that not many hospitals and medical centres can afford these devices. For example, Da Vinci surgical system costs around 2,5 million euros, along with annual maintenance price of 150 thousand euros makes that an average cost per operation is almost 8 thousand euros [22]. In surgery robots, the price is affected by the need of FDA approval, which is very costly, but that does not mean that non-surgical robots are cheap. The estimated price of TUG robot is 140 thousand euros, with additional maintenance costs plus we need to mention, that most hospitals need to edit their layouts to secure unobstructed pathing [23]. Another disadvantage worth mentioning is their problematic adaptation, as neither hospital staff nor hospital premises are ready for robots.

All in all, robots for medical applications have come a long way since their first use in 1985. Their undoubtable benefits reach to almost all sections of this field and it is expected, that in the future, the humanity will be even more dependent on their services. However, before their full potential can be reached, the drawbacks that have been already mentioned need to be solved.

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