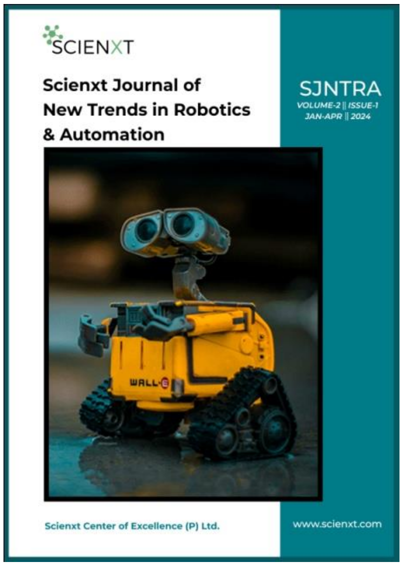

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Applications of mechatronics in medical field: a review

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Abstract:

Medical field is no longer dependent on older technologies. It has developed a lot. In every field of medical a remarkable progress have been done. In healthcare, mechatronics accelerated various technologies by developing devices, equipments, and systems that enhanced the delivery of medical services. The main objective of mechatronics is for designing and creating smart machines and smart products, leading to innovations of robotic surgical instruments, intelligent positioning beds, exoskeletons, care robots, hospital robots, and life-saving medical devices like pacemakers, defibrillators etc. Mechatronics have made remarkable progress from a-z different areas of medical field.

1. Introduction:

Mechatronics is an area where it is integration of mechanical engineering, electrical engineering, electronic engineering and software engineering. With passage of time different engineering areas have developed and led to improvements in mechatronics area. Mechatronics have improved in all areas like industries, defence, space studies etc.

1.1. Advantages of mechatronics:

1.1.1. Enhanced accuracy and precision:

Mechatronic engineering can enable the development of devices and systems that can perform tasks with high precision and accuracy, such as surgical robots, drug delivery systems, and biosensors. These tools and systems can reduce human error, improve patient outcomes, and save time and money. [1]

1.1.2. Increased efficiency and productivity:

Mechatronic engineering can improve the efficiency and productivity of healthcare processes and workflows, including data collection, analysis, and communication. For example, mechatronic engineering can use robotic process automation (RPA) to automate administrative and clinical tasks such as scheduling, billing, and reporting. This can save staff time, reduce errors and increase patient satisfaction. [1]

1.1.3. Improved accessibility and affordability:

Mechatronic engineering can make healthcare more affordable and accessible to a wider population, especially in remote and low-income areas. For example, mechatronic engineering can enable the use of telemedicine and mobile health to deliver healthcare services and information through digital platforms such as smartphones, tablets, and wearable devices. This can improve the availability and accessibility of healthcare, reduce travel and transportation costs, and empower patients to manage their own health. [1]

1.1.4. Enhanced safety and security:

Mechatronic engineering can improve the safety and security of healthcare devices and systems, such as medical implants, prosthetics and electronic health records. For example, mechatronic engineering can enable the use of biometric authentication, encryption, and blocking to protect the privacy and integrity of health data and processes. This can prevent unauthorized access, counterfeiting and fraud, and ensure compliance with regulations and standards.

1.2. Disadvantages of mechatronics:

1.2.1. Expensive to set up:

One of the disadvantages of mechatronics is the cost of building the system. Mechatronics systems require multiple components and complex hardware to acquire and analyze data from multiple sources. This requires considerable engineering skills and considerable computing power. [2]

1.2.2. Requires regular management:

Mechatronics is an advanced form of automation that combines mechanics and electronics to create more efficient and reliable automated systems. However, this system requires a significant investment in time and money to maintain and operate. The biggest drawback of mechatronic systems is the constant need for maintenance. Because the system has multiple components that must be synchronized to function properly, any short-term failure can be frustrating and time-consuming. [2]

1.2.3. Complicated to operate:

One of the disadvantages of mechatronics is that it can be very complicated to operate. This requires deep knowledge of various topics and deep understanding of various components and functions. [2]

1.2.4. Potential for security breaches:

Security breaches and possible unauthorized access to mechatronics-related data and systems are significant weaknesses. Security breaches related to mechatronics are mainly related to the use of network systems and digital data for various systems and tasks. Malicious actors can exploit security vulnerabilities to gain access to data and systems on such systems. [2]

1.2.5. Lack of transparency:

Lack of transparency in mechatronics can lead to a variety of defects, from stalled projects to product failures and customer dissatisfaction. The problem often arises from the relationship between the designer and the engineer planning for the system and how it works in the field. By fully understanding the architecture of the system, it can be easy to predict how the system will behave in certain situations or determine the type of disease that causes certain problems.

In medical field mechatronics have revolutionized. There are different areas of medical field where mechatronics have benefitted as shown in Fig. 1. [2]

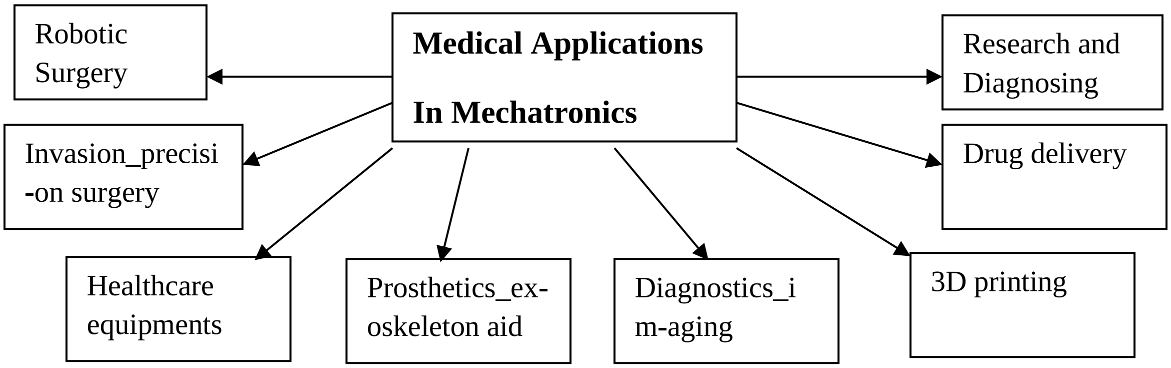

Figure. 1: Mechatronics in Medical field [3]

2. Applications in medical field:

Fig. 1 shows the various applications of mechatronics in the medical field. Various healthcare scientists/surgeons in each field have made significant contributions and are presented in this section.

2.1. Applications of mechatronics in robotic surgery:

As part of this application, it increases the skill and precision of surgeons during operations by using a combination of robotic arms, cameras and advanced software that allows surgeons to perform complex operations with incredible precision. Using these technologies, surgeons can perform highly sensitive and risky procedures. [3]

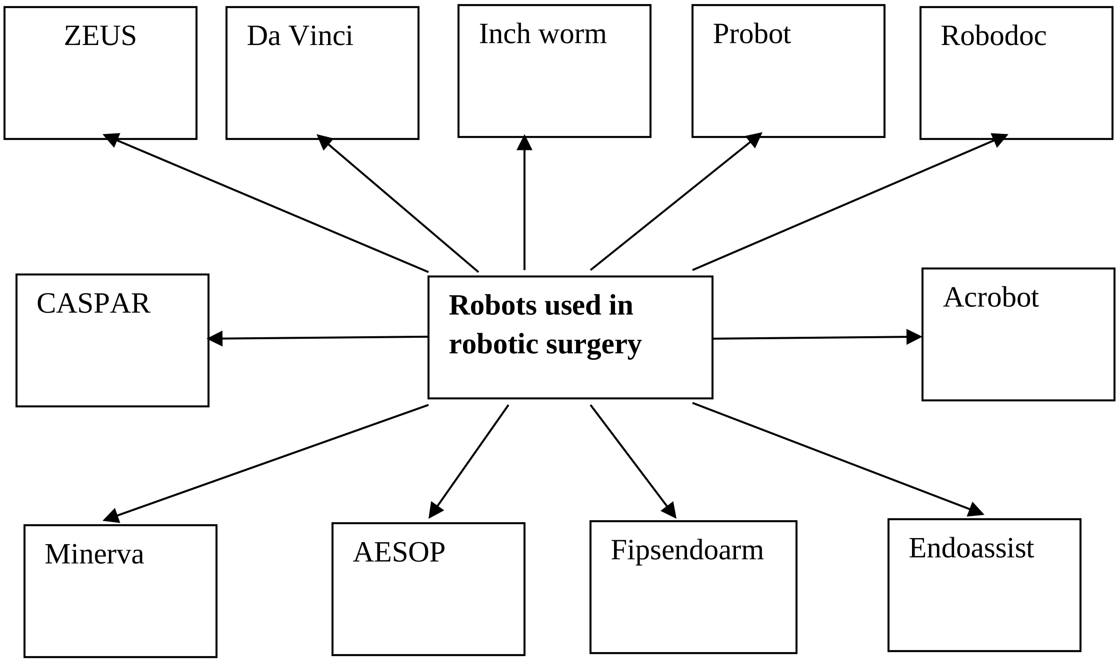

Figure. 2: shows different robots used in robotic surgeries [56]

Some of the works done by people are as follows:

Robot technology improves operations by increasing accuracy, stability and speed. In image-guided procedures, robots use magnetic resonance and computed tomography image data to guide instruments to the treatment site. This requires new algorithms and user interfaces for planning procedures; also requires a sensor to register the patient's anatomy with preoperative imaging data. The minimally invasive procedure uses a remote-controlled robot that allows surgeons to operate without making large incisions in the patient's body. Special mechanical designs and sensing technologies are required to improve speed under these input constraints. Robots have applications in many surgical specialties. In neurosurgery, image-guided robots can biopsy brain lesions with minimal damage to adjacent tissue. In orthopedic surgery, robots are routinely used to shape the femur to fit a prosthetic kidney replacement. Robotic systems are also being developed for closed thoracic bypass, microsurgical procedures in ophthalmology, and surgical training and simulation. Although initial clinical trial results are positive, clinician recruitment, cost base, performance testing, and safety issues remain to be addressed. [4]

In [5] the authors provided an analysis of current surgical technology and expertise, identifying what the next generation of surgical equipment and technology should achieve, then reviewed the evolution and current state of surgical robotic solutions and assessed how they responded to future surgical needs. Finally, the US military reported on their experience with surgical robots and lessons learned.

In [6] authors reviewed the history, development, and current applications of robotics in surgery.

When robots were first used in the operating theater 25 years ago, a major positive step was taken in the field of surgery. The robot was a PUMA 200 (Westinghouse Electric, Pittsburgh, PA) used for needle placement in CT brain biopsies. Since then, it had been exciting to watch the robotic surgery industry growing through leaps and bounds. Part of the reason for this was the advantages that robots offered that were not available in traditional surgical techniques. For example, robots had offered stability, accuracy, integration with modern imaging technology, greater mobility, and telesurgery, in addition to many advantages unique to specialized surgical specialists. Since the introduction of robotic surgery, many advances had been made in this field. To exploit the potential of surgical robots, it was important to understand the past in order to build the future. To understand the past, it was important to look at the progress and achievements in various fields of robotic surgery, including otolaryngologic, neurosurgery, gynecologic, cardiothoracic, gastrointestinal, urologic, orthopedic, endoscopy, and miniature with anticipated future progress could be assessed. This article lists important milestones and continues with limitations in the next article. [7]

In [8] the authors reviewed the field of surgical robotics, focusing on important milestones and classifying several proposals. The review was not exhaustive, but was intended to show how surgical robots acted as a viable technology for minimally invasive surgery. As such, attention had been focused on commercially available robotic surgery solutions; Research studies that had not received regulatory approval or had not entered clinical use are often included. Robotic surgery practice is currently dominated by the da Vinci system from Intuitive Surgical (Sunnyvale, CA, USA), but other commercial players have entered the market with surgical robotic products or are on the horizon with mid- and long-term offerings. Today, surgical robots are a lively research topic, and new research directions may lead to the development of small, special-purpose, inexpensive, disposable robots in the future, rather than large, versatile, and capital-intensive systems. As the trend towards minimally invasive surgery (MIS) increases, surgeons become more technically demanding and medical device technology more challenging, and it is clear that surgical robots take a central place in medicine as the enabling technology for MIS.

In [9] authors reviewed the current use of robotically assisted surgery, focusing on technology as well as main applications in digestive surgery, and future perspectives.

Since the mid-1980s, the development of medical robots had been impressive. From early efforts in stereotactic brain surgery, orthopedics, endoscopic surgery, microsurgery, and more, that trade spaned commercial markets, clinically embedded systems, and a strong and rapidly growing research community. This [10] article discussed some important topics and illustrated them with examples from current and previous research. Further reading provided a more complete overview and recommendations for this rapidly expanding field.

2.2 Applications of mechatronics in invasive and precision surgeries

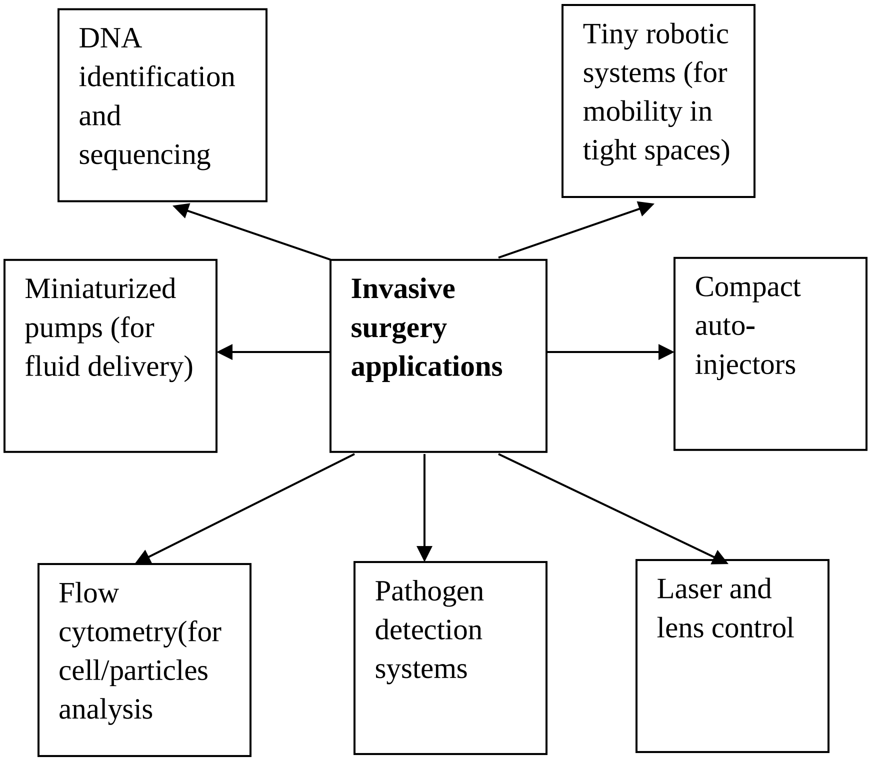

Figure. 3: shows different applications of invasive and precision surgery [3]

Some of the works done on invasive and precision surgeries are as follows:

Minimally invasive surgery (MIS) challenges the surgeon's skills by removing the surgical field, which can only be reached with long instruments. Therefore, the surgeon loses access to the manipulative force on the patient. This slows down the operation. A new compact and lightweight robot for MIS to measure manipulative forces had been introduced. The main advantage of that concept was that no miniature force sensors need to be attached to surgical instruments and implanted in the patient. Instead, a standard sensor was attached to a modified trocar that allowed unobstructed manipulation force measurements outside of the patient. That approach reduced costs and sterilization requirements. Results of in vitro and in vivo power control experiments were presented to confirm the concept. [11]

Recent technological advances in surgery had led to the development of several new techniques that reduced patient trauma, shorten hospital stays, and improve diagnostic accuracy and treatment results. Despite the many-appreciated benefits of minimally invasive surgery (MIS) compared to conventional approaches, there were significant drawbacks associated with conventional MIS, including ergonomics caused by rigid instruments and rigid instruments. The use of robotic assistance had helped realize the full potential of MIS with consistency, safety and accuracy. The development of clear, precise instruments to increase surgeon flexibility had grown in parallel with advances in imaging and human-robot interaction. It improved hand-eye coordination and manual precision down to the micron scale with the ability to cross complex anatomical paths. . [12] Discussed the clinical requirements and technical challenges related to the design of robotic platforms for endoscopic surgery. Technical approaches and engineering challenges related to instrument design, internal guidance, and human-robot interaction were reviewed. The authors also highlighted emerging designs and research opportunities in the field by evaluating current limitations and open technical challenges for the broader clinical development of robotic platforms in MIS.

Many surgical procedures are now performed using minimally invasive surgical techniques (MIS), where unnecessary trauma is limited to reducing the size of incisions to less than 1 cm or to vessels, gastrointestinal or indwelling catheters or endoscopes or other pipe structures. Micromechatronic technology has great potential to improve the surgeon's capabilities in applications that do not allow access to areas currently inaccessible or the full scope of current minimally invasive techniques. In [13] authors identified the basic needs and applications in MIS and discussed the technologies, methods, and related system problems in mechanical equipment. The authors used a millirobotic system for abdominal MIS.

Ref. [14] described a hand-held mechatronic device for minimally invasive surgery (MIS) to assist surgeons in various surgical procedures and improve their (speed) and sensitivity. The main feature of the device was to limit the risk of damage to biological tissue in most manipulation procedures (dissection, roughening, traction, extension and cutting) involving actuators and tools that helped the surgeon perform that surgical procedure. For that purpose, mechanical devices were equipped with embedded microcontrollers and working force sensors, which provided closed-loop force and torque control of the device-network interaction. By directly controlling the perception and interaction force, the surgeon could selectively manipulate the tissue with the application of the applied force based on the surgical needs and tissue consistency. In particular, .[14] discussed the design steps carried out in the MATLAB / Simulinktrade environment and carried out through a virtual prototyping approach consisting of kinematic, dynamic modeling and control system synthesis. The advantage in simplifying the surgical procedure was the result of the sero-assisted nature of the device, which was demonstrated by using the prototype version of the device in a simulation performed by participating pelvic trainers and complex tasks such as sewing and tying knots.

In [15] the authors described the design features of an innovative fully integrated camera candidate for minimally invasive abdominal surgery with a single port or transluminal access. The device included a CMOS image sensor, a light-emitting diode (LED)-based device for scene illumination, a photodiode for light detection, an optical system designed based on the mechanical compensation paradigm, an automatic focus and optical zoom motor unit, and a microcontroller-based control logic. The main body of that device was characterized by a tube shape with a diameter of 10 mm and a length of 35 mm. The optical system, which consisted of four lens groups, had a total length of 13.46 mm and an effective focal length of 1.61 to 4.44 mm, a magnification factor of 2.75 ×, with a corresponding angle range from 16 ° to 40 °. The mechatronic unit for activating the zoom and focus lens groups was implemented using miniature piezoelectric actuators. The control logic implemented a closed loop mechanism between the LED and the photodiode to achieve automatic control of the light. Design flaws and some potential implementation issues were discussed. Possible clinical scenarios were included.

Conventional ultrasound-assisted minimally invasive surgery has reached surgeons for its high accuracy in hand-eye coordination. A possible solution to reduce this requirement is minimally invasive surgery with a robot, guided by visual feedback to the target set by the surgeon on ultrasound. In [16] the authors developed a radiofrequency ablation medical robotic system to help surgeons effectively treat patients with liver tumors. Medical robots could control tissue machines to accurately track tumors in real time. The operating room, the clinical operation requirements and the optimal mechanical structure of the robot requirements were the main factors in designing a suitable medical robot structure for the surgeon at work. The linearity and uncertainty of tumors required an accurate management system able to manage and localize tumors in real time and guarantee survival. Kinematic modeling and analysis were performed to calculate the kinematic solution. The test results showed the reliable performance of the medical robot system and could help surgeons operate the tissue ablation device, which was a minimally invasive operation that was highly dependent on the experience of the surgeons. The development of medical robotic systems had contributed to the promotion and spread of minimally invasive surgery.

Minimally invasive surgery (MIS) had been proven to be beneficial in providing excellent results for patients. However, studies had shown that surgeons face significant challenges in performing that type of procedure, ranging from poorly designed instruments to the surgeon due to awkward postures. More ergonomic surgical instruments that implement mechatronic features had been proposed, which was based on the critical need to develop surgical instruments that fully meet the needs of surgeons when using MIS techniques. That concept device aimed to reduce postoperative injuries and improve the kinetic skills during surgical procedures, increasing the speed and accuracy of the work performed. [17]

2.3 Applications of mechatronics in healthcare equipments

According to this application, it provides mobility and adaptability, facilitating efficient and comfortable patient transport; ensuring the comfortable position and comfort of the patient during the medical examination contributes to the accuracy and flexibility of the examination trainer; more versatile, making adjustments easier to meet specific patient needs, thereby improving overall care; managing and fine-tuning the control system, resulting in improved quality and accuracy of diagnostic procedures. [3]

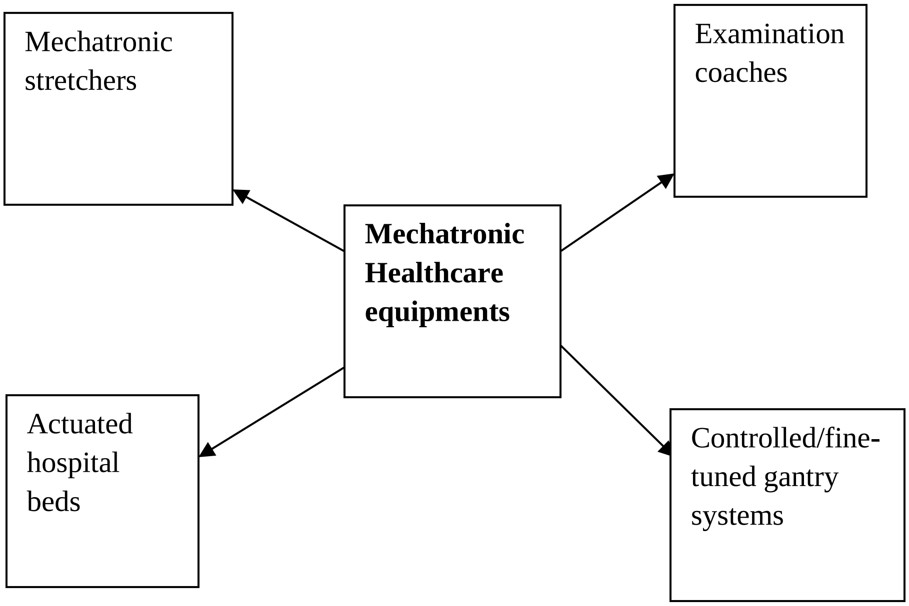

Figure. 4: shows different equipments medical equipments made by using mechatronics [3]

Some of the works done in the field of healthcare equipments are as follows:

In [18], the authors discussed the mechanical design and mechanical control of a multipurpose test bed to test and evaluate healthcare interventions designed to help bedridden people. The test bed consisted of two robotic beds: a basic bed and a nursing bed. The main bed was intended to change the posture and transport the bed of the elderly. Both beds were equipped with a belt system to move the body between them. The design concept of that bed system was based on field studies of similar equipment in hospitals. The two beds were then created and controlled by a sequentially developed mechanical system that could be interacted with through a specially designed graphical user interface program. Relevant experiments had shown a lot. The proposed test bed was intended for mechanical engineers and health professionals to help sleepers in their daily lives. The evaluation results showed the effectiveness of the bed system.

The critical situation of COVID-19, which had spread in Peru since the beginning of 2020, had been aggravated by avoiding social distancing seen in crowded public places without personal protective equipment (PPE), which puts many people at risk of contracting it with virus.Therefore, in 2020, innovative research was carried out under the supervision of the Laboratory of Mechatronic Engineering of Ricardo Palma University and the Bioastronautics and Space Mechanics Research Group, which led to the proposal of a project called ROHNI-1 Medical Robot as a Social Humanoid machine. It was located at the entrance of the grocery supermarket. It consisted of 3 wheels on a chassis base and 2 anthropomorphic legs of 4 DOF each. It could develop 3 functions such as mask detection, hand disinfection and vital sign monitoring to realize effective human-machine interaction. The study presented mechatronics conceptual design using SolidWorks 2020 software to develop 3D mechanical systems, Proteus 8 for electrical and electronic circuit schematics, and Matlab 2020a software for kinematic motion testing of robot arms. In conclusion, favorable simulation results were obtained; the production of the robot was expected to be ready by 2021, and due to the analysis of innovative cost-effective engineering, it was planned to be donated to Latin American countries with supermarket chains. [19]

The health of the elderly today receives special attention and attention to improve their well-being and quality of life. Research on various aspects of elderly care had found that it should focus on addressing problems related to bathing in different situations and environments. In particular, it is important to develop new assistant technologies to facilitate and facilitate the daily tasks of caregivers. In general, bathing for bedridden patients is usually done manually by the caregiver with a towel, sponge, and basin. However, that simple task required some precautions to prevent germs, falls and other injuries. With this in mind, [20] the authors presented the design of a portable bath system called Mandi-Ambience, which allowed bedridden patients to bathe effectively without having to move from their position. This portable system could be installed in various settings, indoors and in special institutions, and would allow the caregiver to do the task of bathing without compromising health and safety, thus offering patients a comfortable and hygienic procedure, improving the quality of life. The authors presented the design of a portable toilet system that effectively helped bedridden patients to bathe without having to move them. This system was mainly dedicated to integrating a smart home application for any bathroom.

The ever-increasing percentage of elderly people in developed countries has made Ambient Assisted Living (AAL) solutions an important issue to explore and develop. The increasing demand for geriatric care placed a heavy burden on specialized agencies that cannot meet the demand for support. Patients are often forced to leave their partners or close family members in their homes as caregivers. This caregiver is not always physically and technically fit to help bedridden people with eating and hygiene / bathing routine. Ultimately, solutions to help these patients and problems are essential. In [21] the authors presented an approach to support caregivers when they moved and placed people without beds (BEPs) in the home environment using a mechatronic system inspired by industrial conveyors. The proposed solution could penetrate below the patient, took and distributed it due to its low-level structural features. Ideally, the proposed mechanistic system aimed to promote autonomy by reducing operational complexity, changing the caregiver's role from physically controlling the BEP to the role of operator/supervisor, and reducing the effort expended by caregivers and BEPs.

In this chapter [22], the author focused on low-cost mechatronic solutions for home care of the elderly and people with reduced mobility to help people in their daily lives. The development of such a system was flexible and could be used as a tool or device that could be used in rehabilitation or an auxiliary system, helping movements with controlled position, force / torque and acceleration, potentially introducing reliability, repeatability and inferiority. Costs in related industries. In particular, the development of a low-cost control system design allowed the use of solutions for a variety of home maintenance equipment. The authors aimed to develop a low-cost technology for elderly and motor-impaired households seeking to significantly reduce overall costs to facilitate the use of assistance and rehabilitation systems. In particular, the Sit-To-Stand (STS) assistive device was taken as a paradigmatic example to demonstrate design considerations.

Healthcare demand for hospital beds is a concern in private and public institutions. The conventional bed is hard and does not take into account the caregiver's health and stress, and the patient's discomfort, which affects the healing process. For this reason, the SmartBed mechatronic system was proposed with a user-friendly interface that allowed patients and caregivers to move the bed into complex situations that improved the quality of life and reduced the risk of death. In this paper [23], the design and development process of SmartBed, with special emphasis on the interactive user interface to control the system, presented the initial results of the interaction between test subjects and hospital beds.

2.4 Applications of mechatronics in prosthetic and exoskeletons aid:

This application includes designing advanced prosthetic limbs and exoskeletons that increase mobility and functionality; add sensors, actuators and microcontrollers to improve the natural movement of human limbs, thereby improving the quality of life for amputees and people with mobility impairments; implanting complex, active prosthetic limbs, prosthetic hands and fingers that allow people to grasp and manipulate objects with exceptional dexterity and precision. [3]

Some of the works done by people in area of prosthetic and exoskeletons are as follows:

Lower limb biomechatronic devices (i.e., prostheses and exoskeletons) depend on onboard batteries, wearable sensors, actuators, and microprocessors, limiting their operating time. Regenerative braking, also known as electric power regeneration, represents a promising solution for the aforementioned shortcomings. Regenerative braking converts mechanical energy otherwise dissipated during locomotion into electrical energy to charge the battery, while providing negative mechanical work to decelerate the controlled system. In the authors reviewed the electromechanical design and optimization of low-energy biomechatronic devices with electrical energy regeneration. The technical review began by examining the biomechanics of human walking (i.e., mechanical work, forces, and torques at the hip, knee, and ankle joints) and proposed general design principles for reprosthetics and exoskeletons. Similar to electric and hybrid vehicle propulsion, there are many mechanical design components that can be optimized to maximize electrical energy recovery, including mechanical power transmission, electromagnetic engines, electric motors, device mass and moment of inertia, and energy storage devices. The design optimization of the system components was discussed in particular with reference to recent developments in robotics and automotive engineering. A technical review showed that the existing system was (1) limited to surface travel applications and (2) had a peak energy recovery efficiency between 30% and 37%. Accordingly, future directions for research and innovation included: (1) regenerative braking during dynamic movements such as sitting, leaning, and descending stairs, and (2) high torque density electromagnetic engine and low-impedance mechanical power transmission to improve energy regeneration efficiency.

Research on the development of lower limb bones began in the 1960s. However, the development of that robotic device technology has slowed down despite long-term studies. Hence the purpose of this article [25] was to document a systematic review of trends in the use of components that were part of the development of exoskeleton for lower limb therapy. The goal was to provide researchers with a structured matrix that integrated components related to the development of lower limb bones. As a method, authors used several databases and specialized search engines that helped them collect research from 2016 to 2020. A screening and selection process was carried out for the reviewed studies, and 90 were selected. Finally, it was concluded that there was still room to improve and develop the bones of the lower limbs which contribute to the recovery and are closer to the actual function of the lower limbs.

Recently, robotic devices have become human companions, and the use of robotic devices to help the physically challenged shows encouraging signs of clinical application of that investigative technology. However, until now, exoskeleton design can be considered an obstacle, even with modern robotic devices, helping patients who have lost limbs or are injured is one of the most challenging goals. In [26] research conducted by the Department of Industrial Engineering of the University of Florence aimed to develop portable, wearable and highly customizable hand exoskeletons to help patients with hand disabilities and determine patient-centered design with strategies for customizing tools according to different user needs. A version of a three-armed exoskeleton was presented in [26], showing a key step in the design of compact and lightweight mechanical and control solutions. The performance of the obtained system was tested in a real usage scenario. The results obtained were satisfactory, indicating that the obtained solution could be a valid alternative to the hand braces that had been studied so far in the field of rehabilitation and rehabilitation.

Taking inspiration from autonomous vehicles, future use of environmental data could improve the control of biomechatronic devices that can be used to assist human positioning. According to the authors, this ref. [27] presented the first documented analysis using machine vision and deep convolutional neural networks for environmental recognition to support predictive control of robotic lower limb prostheses and exoskeletons. One participant was equipped with a battery-operated, chest-mounted RGB camera system. About 10 hours of video footage was collected during the experiment in an ambulatory setting in unknown outdoor and indoor conditions. Captured images were pre-processed and tagged. A deep convolutional neural network was developed and trained to automatically recognize three walking environments: ground level, steep stairs, and descending stairs. The environment recognition system achieved an overall image classification accuracy of 94.85%. Expanding that initial result, future studies had included other environmental classes (e.g. inclined ramps) and combined environmental recognition systems with electromechanical sensors and/or surface electromyography to recognize automatic locomotion modes. Issues related to implementing deep learning in wearable biomechatronic devices were discussed.

Active upper arm exoskeleton robots had been developed since the 1960s. In recent years, the mechanical design and control algorithms of active exoskeleton robots had improved significantly.

This ref. [28] reviewed the state-of-the-art advanced exoskeleton robots used in the field of rehabilitation and assistive robotics. In addition, the basic requirements of active upper exoskeleton robots were identified and the mechanical design of existing upper exoskeleton robots was classified. Design challenges for functional upper exoskeleton robots were discussed.

Robotic lower limbs have been developed to improve human abilities, assist the disabled, study human physiology, and retrain motor deficits. At the University of Michigan Human Neuromechanics Laboratory in [29], the authors developed a pneumatic lower arm prosthesis for the latter two purposes. Much previous research had focused on ankle joint exoskeletons because of the large contribution of the plantar flexors to the mechanical work performed during walking. A method of controlling exoskeletons with proportional myoelectric control effectively increased the wearer's strength through physiological control. Healthy human subjects quickly adapted to walking with robotic ankle exoskeletons, reducing overall energy expenditure. Individuals with complete spinal cord injuries showed rapid changes in muscle recruitment patterns when walking with ankle exoskeletons. Evidence suggested that proportional myoelectric control might have distinct advantages over other types of control for robotic exoskeletons in basic science and rehabilitation.

Ref. [30] first presented a humanoid lower limb exoskeleton (HLLE) actuated by pneumatic prosthetic muscles. It was almost anthropomorphic and retained six degrees of freedom (DOF) for each lower limb. Pneumatic artificial muscles (PAM) were designed and manufactured according to McKibben's proven principles to obtain basic static performance. Then, a pulse width modulation (PWM)-self-tuning PID (FSPID) control was proposed to control the motion of HLLE, an efficient strategy that did not rely on the lower limb kinetic model. In addition, inertial measurement units (IMUs) had been installed in some components to obtain accurate motion parameters in time, intended to obtain useful motion results. As the control center of the system, the microcontroller unit (MCU) was mainly responsible for communicating with sensors and computers, controlling valves and generating PWM signals for data processing. When using HLLE, it was expected to obtain an effective intelligent control strategy for PAM and downstream members. The results of that study were applied to the human body using HLLE in the future. Finally, the author's research had contributed significantly to the application of pneumatic artificial muscles in various fields, including smart prosthetic devices, medical care exoskeleton, and powered exoskeleton. Finally, [30] provided a summary of expected work for further experimental studies.

2.5 Applications of mechatronics in diagnostics imaging systems:

This application enables the production of high-resolution images that aid in the detection and diagnosis of various medical conditions using magnetic resonance imaging (MRI), computed tomography (CT) and ultrasound machines. [3]

Some of the work done by people in image capturing for diagnosing are as follows:

The continuous technological progress of magnetic resonance imaging (MRI) as well as its widespread use as a highly sensitive tool in diagnostics and brain research had created a great demand for the development of magnetic resonance (MR)-compatible robotics / mechatronics. System. The revolutionary robot guided by true three-dimensional (3-D)-MRI had enabled safe and precise minimally invasive procedures with short recovery time. Dedicated robotic interfaces used in conjunction with fMRI had enabled neuroscientists to study brain manipulation and motor learning mechanisms, as well as to improve rehabilitation therapy. In ref. [31] authors provided an overview of the motivations, advantages, technical challenges, and existing prototypes for MR-compatible robotic/mechatronic devices.

In [11], the authors proposed a three-dimensional (3D) multimodal medical imaging system without the need to combine free ultrasound and 3D reconstruction of structured light. To authors knowledge, that method had not been combined as a multimodal imaging technique. The system complemented the internal 3D information obtained by ultrasound with the external surface measured using structured light techniques. In addition, ultrasound optical tracking for pose estimation was based on convolutional neural networks. The test results showed the high accuracy and reproducibility of the system, as well as the ability of preoperative and intraoperative applications. The error of the multimodal test, or the interfacial distance obtained by different methods, was 0.12 mm. The code was available in the Github repository.

Photoacoustic imaging had attracted considerable attention due to its unique functional, metabolic, and molecular imaging capabilities achieved by the combination of optical excitation and acoustic detection. With the strong advantages of light and ultrasound, photoacoustic imaging can provide strong optical contrast in deep tissue ultrasonography. Because photoacoustic imaging can be used to visualize information in addition to ultrasound through the same data acquisition process, several studies had been conducted to integrate photoacoustic imaging with existing clinical ultrasound systems. Ref [33] presented the development of a dual photoacoustic/ultrasound modal imaging system, various features and functions made for clinical translation, and preclinical/clinical studies using the system.

In ref. [34] authors reconstructed a three-dimensional (3D) model of the human body by using CT slices and digital images and accurately locating pathological structures such as tumors. 3D CT image reconstruction had become an interesting field in digital image processing techniques, especially in biomedical imaging. Almost all modern tomographic techniques had been intensively developed and implemented in practice, but there were still many problems that remained unanswered or could be improved. Projects had been developed in that area with the aim of mastering the technologies mentioned above and developing domestic products that were partial substitutes for expensive imported facilities and software. In [34], Martining Cubes (MC) algorithm, normal representation method, etc. were presented with the main problems in the reconstruction of 3D medical images for medical imaging and developing software for the reconstruction of 3D images from CT image sets. Built on VTK (Visualization Toolkit) and Visual C++. Finally, it was shown that the reconstruction software could help reconstruct a series of 2D segmented binary images and made a 3D image of the target object.

Medical imaging refers to a number of different technologies that are used on the human body to diagnose, monitor, or treat medical conditions. Each of these technologies requires significant expertise in radiography, ultrasound, and magnetic resonance imaging to effectively and accurately interpret the resulting images. Deep learning techniques and machine learning provide solutions related to medical image interpretation and detection and diagnosis. Despite the tremendous success of deep learning algorithms in image analysis, to achieve human-level performance in that problem, training algorithms depend on the availability of large amounts of high-quality training data, including high-quality features to be used as ground truth. Interpretation tool had been developed to assist in various interpretation processes. In ref. [35] the authors presented annotation tools currently available for medical imaging, including the description of graphical user interfaces (GUIs) and support tools. The main contribution of their's research was an in-depth review of popular annotation tools and demonstrated their successful use in annotating medical imaging databases to guide researchers in the field.

Computer vision, biomedical image processing and deep learning are related fields with a huge impact on the interpretation of medical images today. Among biomedical imaging modalities, ultrasound (US) is one of the most widely used in practice because it is non-invasive, accessible and inexpensive. Its main disadvantage compared to other imaging modalities such as computed tomography (CT) or magnetic resonance imaging (MRI) is the increased dependence on a human operator. One important step to reduce this dependency is the implementation of a computer-aided diagnosis (CAD) system for imaging in the US. The objective of ref. [36] was to investigate the application of contrast-enhanced ultrasound imaging (CEUS) to the problem of automatic diagnosis of focal liver lesions (FLL) using deep neural networks (DNN). Custom DNN designs were compared to state-of-the-art architectures, either pre-trained or trained from scratch. It improved and extended previous work in that area in several aspects, e.g. a new leave-one-patient-out scoring procedure, which further allowed the authors to formulate a classification scheme based on hard voting. They demonstrated the effectiveness of their models, i.e. 88% accuracy reported against a higher number of liver lesion types: hepatocellular carcinomas (HCC), hypervascular metastases (HYPERM), hypovascular metastases (HYPOM), hemangiomas (HEM) and focal nodular hyperplasia (FNH).

2.6 Applications of mechatronics in 3-D printing of medical components:

Under this application, printing extend to printing an array of vital components, including stem cells, blood vessels, heart tissues, prosthetic organs, and even skin. [3]

Some of the works done on printing medical vital components are as follows:

Physical organ models are objects that reproduce patient-specific anatomy and play an important role in modern medical diagnosis and treatment. As a powerful multifunctional manufacturing technology, 3D printing breaks the limitations of traditional methods and offers great opportunities to produce organ models. However, the clinical application of organ models still faces challenges such as large scale, high cost, low simulation performance, and insufficient accuracy. In the ref. [37] authors introduced the main 3D printing technology and divided it into "direct printing" and "indirect printing", focusing on available manufacturing methods, appropriate techniques and material selection. The authors also summarized the ideas to solve those challenges and focused on three issues: 1) the characteristics and requirements of organ models in different application scenarios, 2) how to choose 3D printing methods and materials based on different application categories, and 3) how to reduce model costs organs and processes should be simple and convenient. In addition, the state-of-the-art in organ models was summarized and the contribution of 3D printed organ models to various surgical procedures was demonstrated. Finally, current limitations, evaluation criteria, and future prospects for this emerging area were discussed.

Over the past few years, people have reinvented themselves on the far side of their current physical and mental limitations. This development is understood as transhumanism. In robotics and biomimetics, different styles of physical structures were used with the aim of creating applications such as artificial humans. While the lower extremity medical profession has grown to the point where lower limb amputees can compete against the world's top runners, there is a clear distinction between upper extremity medical specialists and right hands. Ref. [38] aimed to develop a cheap, lightweight and strong 3D printed prosthetic arm and talked about the development of prosthetic arms, mechanical devices, and full integration of movements. In addition, [38] showed progress in data classification using electromyography (EMG) signals from the arm, providing flexibility to standardize the diagnostic method of prosthetic arm surgery. In addition, [38] aimed to contribute to the growth of the human-golem combination by raising students to participate in transhumanist studies through more refined technologies and methods.

Myocardial remodeling, including ventricular dilation and wall thinning, is an important pathological process induced by myocardial infarction (MI). To join this pathological work, a new type of cardiac scaffold composed of thermoset (poly-[glycerol sebacate], PGS) and thermoplastic (poly-ε-caprolactone, PCL) was directly printed using a 3D composite deposition model and printing technology. The PGS-PCL scaffold had a structure covered with continuous cut filaments and interconnected micropores and exhibited high mechanical properties. In vitro studies showed favorable biodegradability and biocompatibility of the PGS-PCL scaffold. When inserted into the infarcted myocardium, that scaffold improved and maintained cardiac function. In addition, the scaffold improved some important aspects of myocardial regeneration. At the morphological level, Scaff reduced thinning of the ventricular wall and infarct enlargement, while at the cellular level, it increased vascular density and increased the infiltration of M2 macrophages, which could contribute to a decrease in the rate of myocardial apoptosis. In addition, the flexible PGS-PCL scaffold could be tailored to any desired shape, showing promise for the use of an annual shape-limiting device, meeting the requirements of minimally invasive surgery. Overall, that study demonstrated the therapeutic effects and versatile applications of a novel 3D-printed, biodegradable, and biocompatible cardiac scaffold that represented a promising strategy to enhance myocardial regeneration after MI. [39]

Among the various manufacturing processes used in industry today, 3D printing stands out as a unique additive method. It allows creating three-dimensional solids of almost any shape from digital models. Medical 3D printing has become a reality thanks to significant time and investment, initially considered an ambitious concept. This ref. [40] explored the latest developments in 3D printing in the modern medical field and provided an overview of how and why 3D printing was changing medical practice, education, and research. This was an introduction to the subject and a state-of-the-art demonstration through the latest developments in the industry. The importance of this ref. [40] covered the growing role of 3D printing in healthcare, not only showing current applications and challenges, but also it’s potential to transform various aspects of medical science and patient care.

Ref. [41] basis was robotic arms and its implants. This branch of science belongs to mechatronics, or rather bionics. Ref. [41] aimed to build and remotely control a 3D printed robotic arm implant. The robot arm itself was printed with a custom-made 3D printer using biodegradable materials. The finished implant was allowed to interact with other physical objects via remote control. This made it possible to reduce direct physical exposure during a pandemic or work in conditions where the operator cannot stand for a long time without endangering health.

While 3D printing (3DP) has long been an integral part of industries such as aerospace and automotive, its use in healthcare, especially the pharmaceutical industry, is relatively new and is currently receiving a lot of attention. In early 2018, the authors reviewed the 3DP program for drug delivery and drug testing. Due to the rapid development of the industry, it was necessary to summarize the latest developments in that field after 2 years. In [42], the authors reviewed three main areas of clinical practice. First, the drug delivery system was the most studied topic, including controlled-release polypills, gastrofloating, orodispersibles, and microneedles. Second, 3DP helped to develop pharmaceutical equipment, including pharmaceutical dispensing equipment and drug dispensing equipment. Finally, the authors reviewed drug models for drug testing, including cellular and cellular models. The authors summarized the materials used in the cited articles and their regulatory status for pharmaceutical applications to provide references for future research.

2.7 Applications of mechatronics in drug deliverance:

In this application, it is possible to develop advanced drug delivery systems such as insulin pumps, microneedles, microfluidics, nanorobots and implantable drug delivery devices that can precisely administer drugs, provide precise doses and reduce side effects. [3][57]

Some of the works done in delivering drug to target body parts are as follows:

Dental drug delivery systems have long been used, especially for the local treatment of diseases affecting the oral cavity. Current research focused on designing formulations to maximize retention time. However, prosthetic devices that involve drug delivery are rarely used today with main focus on the release of prophylactic and antibacterial agents. However, buccal delivery has gained popularity in systemic drug delivery due to its undeniable advantages, and long-term controlled release has been identified as beneficial, especially for chronic diseases, and a new class of delivery systems is emerging: highly computerized delivery integrated into a dental device system. Dental delivery systems have been used in two ways: the main application is the local treatment of diseases affecting the oral cavity, such as periodontitis or fungal infections. The second is for systemic drug delivery. [43]

In the ref. [44] authors discussed the implementation of a joint engineering approach for microsystem design. A simultaneous engineering or mechanical approach to the design of hybrid microsystems was illustrated through three examples. First, the design of advanced computer typing equipment was discussed. The design of consumer products required a mechatronic approach at different functional levels and at different levels of miniaturization. Another example of that approach had been the design of an implantable drug device. Solid drug delivery devices and liquid drug delivery devices were shown. It had been shown that miniaturization could be achieved through the combination of functions in a single component. The proliferation of functions in a single component had automatically led to an engineering approach away from design. Finally, the micromanufacturing of silicon wafers by electrodeposition was described. Silicon electrodeposition processing had proven to be not only feasible, but also an interesting and complementary technology to conventional silicon micromachining. Therefore, that powerful manufacturing method had paved the way for the integration of true three-dimensional micromechanical sensors and actuators with electronic processing integrated on the same wafer.

Ref. [45] presented a robotic capsule endoscope incorporating a targeted drug delivery module (DDM) for the treatment of digestive diseases. The capsule with a large permanent magnet inside was wirelessly controlled and guided to an area in the digestive tract by an electromagnetic induction system (EMA). DDM was a separate body consisting of a drug container and an inactive drug release mechanism. The propellant was created by the carbon dioxide pressure from the chemical reaction in the engine reservoir where the chemical reaction was activated by a mechanical mechanism that allowed dry chemical powders to come into contact with water at the target point. A small permanent magnet was used to remove the reagent and wet paper before injecting the drug. It was designed to be stable during locomotion with a large permanent magnet attraction. To activate the deposition mechanism, a gradient magnetic field was generated from the EMA system to push a small magnetic slide, allowing the reagent to drop and interact with the water on the wet paper. The proposed DDM was 11 mm long and 11 mm in diameter. Through simulation and ex-vivo experiments, the proposed robotic capsule showed a high potential to be used for the treatment of digestive diseases in practical clinical settings.

MEMS based drug delivery systems have found many applications in modern biomedical engineering. Recent advances in that field have led to the development of advanced techniques in drug delivery systems with maximum accuracy and safety, low energy consumption and cost. As a MEMS device, micropumps have played an important role in targeted drug delivery. Ref. [46] was followed by a review of the history of micropump development and an analysis of different modes of action, followed by several examples of the use of mechanical micropumps in drug delivery applications.

Ref. [47] proposed a novel magnetic standing robot (HR) that could walk on a balloon, deliver drugs to specific sites, and made mechanical screwing motions to close the tubular structure of the human body. The proposed frame consisted of two rotating cylindrical magnets (RM), four cylindrical magnets (FM) and a vertical volume. RMs could be rotated in different directions in two orthogonal external rotating magnetic fields (ERMF). Using those ERMFs, the authors had developed various actions. ERMF along the RMs axis could produce drug release motion, and could produce navigation and torsional motion orthogonal to the ERMF axis. On the other hand, the magnetic torque and attractive magnetic force between RM and FM covered the nozzles in the medicine chamber. The authors analyzed the magnetic moment and magnetic force for navigation, drug extraction, and screw motion. In particular, the drug release motion used the eccentric rotation motion of the RMs due to the attractive and attractive magnetic force between the RM and the FM. The map was squeezed and released the drug. The author had designed the mechanical structure of the proposed frame, taking into account its magnetic properties to achieve the proposed function. Finally, the authors prototyped the scaffold and conducted several experiments to test the scaffold's navigation, drug delivery and drilling capabilities, and confirmed that drug-enhanced drilling could make confined spaces more efficient than simple drilling movements.

There is a growing need to incorporate active controlled drug delivery systems (DDS) into next-generation capsule endoscopy for non-viral treatment of gastrointestinal diseases. Despite several attempts to activate the drug delivery mechanism magnetically in the endoscopic capsule, the longer distance and the miniaturization of the on-board components are still the disadvantages of such systems. The author in [48] used an analytical model to compare the magnetic fields produced by cylindrical and arc magnets. In accordance with the analytical results, the experimental test showed that the optimal arrangement of block magnets increased the magnetic field as well as the induced magnetic moment, resulting in sufficient power to drive the DDS piston and drug dose required from the reservoir. The authors concluded that the proposed magnetic field optimization method was effective in creating an active DDS designed to deliver a drug profile by controlling the release rate, release volume, and dose amount.

The development of magnetically actuated wireless millimeter-scale robots enabled the development of endoscopes. In modern medicine, medicine enters the human body through the mouth and reaches the intestinal tract through the oesophagus and stomach. If the lesion is in the digestive tract, most of the drug is absorbed by other organs and its effectiveness is not increased. In ref. [49] a robot assembly was made which consisted of a front robot and a back robot, each of which consisted of a robot body, a permanent magnet, and a ferrofluid. Permanent magnets were fixed inside the robot, and the rotating electromagnetic field generated by the Helmholtz coils propelled the robot forward. Each robot was injected with Ferro fluid and a compressive force could be generated between two robots using an external magnetic field. Test results showed that the capsule robot could reach the target site for drug release using a rotating magnetic field and an external permanent magnet.

2.8 Applications of mechatronics in research and diagnosing:

Some of the works done by people for studying and diagnosing diseases are as follows:

When a patient needs a blood transfusion in a medical emergency, universal blood type O− is given. This process can lead to depletion of blood O− reserves. Currently, there is no commercial device that can quickly and reliably determine a patient's blood type. Human blood typing is usually done by manual examination, which involves macroscopic observation and interpretation of results by an analyst. This test, despite its fast response time, can cause human error, which can sometimes be fatal for the patient. Ref. [50] presented the development of an automated mechatronic prototype for determining human blood typing (ABO and Rh systems) using image processing techniques. The design of the prototype took into account the reliability of the analysis, portability and response time to allow the system to be used in emergency situations. The developed prototype performed mixing of blood and reagents that took an image of the result and processed the data to identify the blood sample (based on image processing techniques). Laboratory tests were performed using blood type catalog samples provided by the Portuguese Institute of Blood and Transplantation. After that, the prototype was expected to be tested and validated in clinical settings.

Blood type is important for safe blood donation. In an emergency, the blood type "universal donor" is issued. However, sometimes this blood type can cause a mismatch in the transfection receptor. A mechanical prototype was developed to solve this problem. Prototypes were built to meet specific objectives, including all necessary components. The resulting solution was close to the final system that would be produced at a later production level as a medical device. Prototypes were portable and inexpensive devices that could be used in remote locations. Pre-developed computer programs were used to operate advanced mechatronic prototypes and obtain automated test results. They enabled image acquisition, processing and analysis based on Computer Vision algorithms, Machine Learning algorithms and detection algorithms. Machine Learning algorithms had provided a safer and more reliable methodology for the classification of detection or lack of agglutination in the mixture (blood / reagent), because the test data was stored in the database. The work developed allowed the use of suitable blood types in emergency situations, prevented the depletion of "universal donor" blood type stocks, and reduced the incidence of human error in the blood donation process. [51]

Neurodevelopmental engineering is a new interdisciplinary field of research at the intersection of developmental neuroscience and biomedical engineering, primarily concerned with quantitative analysis and modeling of human behavior during neural development. In such a field, the authors in [52] focused on the early diagnosis of neurodevelopmental disorders such as autism, which were often diagnosed after the age of 2-3 years. In an effort to break new ground in the emerging field of developmental neuroengineering, the authors proposed a new approach to assess the basic pattern of goal-directed behavior in infants between 0-24 months of age, both in the laboratory and natural situation. In particular, the authors proposed a novel mechanical device that could be worn or embedded in toys for ecological, visual assessment of infant behavior. Special game design that included both kinematics and force sensing capabilities, as well as instructions to test where similar instrumented games could be deployed. Preliminary tests for technical validation of the initial prototype in ecological conditions were also indicated.

Since the beginning of 2020, Peru had been hit by the inevitable spread of Covid-19, a highly contagious disease that was rapidly spreading throughout the world. Scientists and researchers had proposed several solutions to reduce the effects or reduce the infection, from simple procedures to complex systems such as robots or vaccines. For this reason, from 2020 to 2021, innovative research was carried out under the supervision of the School of Mechatronic Engineering at the Universidad Tecnologica del Peru, in which ref. [53] demonstrated the prototype of the SCARA robot capable of rapid testing of blood samples for the diagnosis of Covid 19. In addition, the robot had 4 servos and an effective end effector. In addition, this robot had 4 degrees of freedom and was chosen for its speed and agility. That study developed mechatronic conceptual design and kinematic analysis using CAD in Matlab and SolidWorks 2021 using the Denavit Hartenberg method. As a result, it was possible to reduce the workload and protect the lives of those who performed laboratory tests, with the possibility of processing with greater accuracy.

Malaria diagnosis is usually performed by visual microscopy, which is time-consuming and offers poor accuracy due to operator fatigue and lack of expertise. To overcome this liability, the authors in ref. [54] developed an automatic system that could automatically image blood vessels at high speed using a motorized compound microscope. After collecting enough samples for microscopy, image processing, which was the core of the author's work, began. Finally, the results of the entire process were reported to the doctor to prescribe the best treatment. Due to the importance of correct diagnostic staging and treatment of parasite species, that system might be of great interest for the diagnosis of malaria.

Blood tests are the most common clinical diagnostic method. Lab-on-a-chip technology, derived from the concepts of microfabrication and microfluidics, provides an automated, rapid, cost-effective and point-of-care solution for a variety of blood tests. Generally, blood sampling is the first step in clinical diagnosis for further blood tests. In ref. [55] the authors studied the rapid prototyping of out-of-plane valves using a low-cost tygon tube inserted into a centrifugal system.

With the new design of out-of-plane valves, such laboratory centrifuge systems could easily separate raw blood into blood cells and plasma. The out-of-plane valve had demonstrated an excellent ability to prevent flow or back-mixing due to diffusion. In addition, the use of tygonal tubes was an easy, reliable, and inexpensive way to create 3D microchannel networks, enabling a rapid conceptual approach to designing lab-on-a-chip devices. Finally, [55] also presented a photolithographic microfabrication process for mass production of Lab-on-a-CD 3D microfluidic devices.

3. Advantages and Disadvantages of mechatronic applications in healthcare:

Table 1. Advantages of mechatronic applications in medical field

Mechatronic medical applications	**Advantages**
Robotic Surgery	Less surgeons required; distanced surgery; decreased trauma and faster patient recovery; less fatigue of surgeons; decreased hospitalization; reduced blood loss and transfusion; greater surgeons' precision.[56]
Invasive and Precision surgery	Reduced trauma; reduced blood loss; reduced infection risk; reduced hospital stay; faster recovery; reduced postoperative pain; reduced risk of hernia; reduced risk of scarring.[58]
Healthcare equipments	Serves effectively for high dimensional accuracy requirements; high degree of flexibility to modify or redesign the systems; excellent performance characteristics; provides the possibility of remote controlling as well as centralized monitoring and control; higher life expectancy.[59]

Prosthetics and Exoskeleton	Improve human strength and endurance in manual work; reduce patients' metabolic energy expenditure during locomotion conditions by reducing active muscle volume usage; help maintain or regain neuromuscular health and provide personal mobility.[60]
Diagnostic imaging(CT, MRI, Ultrasound)	CT: better for bony lesions; medium cost; less risk of irradiation. MRI: Safe due to no usage of radiation; better images and helps to distinguish different tissue types. Ultrasound: safe, noninvasive and does not use ionizing radiation; proper image can be captured; shows clear picture of soft tissues. [61]
3-D printing	Adaptable design; on demand printing; fast prototyping; rapid production and design; reduced wastage; cost effective; sturdy and light parts; easy access; improved visualization; reduced surgical time; increased efficiency. [62]
Drug delivery	Targeted drug delivery to specific sites; maximization of therapeutic efficacy;minimization of off-target accumulation; promotes easy drug absorption; decreased secondary effects; controlled release of drug. [63]

Research and Diagnosing	New treatment and therapies development; remote monitoring and telemedicine capability; personalized medicine development; increased capacity to conduct research; cost savings. [64]

Table 2. Disadvantages of mechatronic applications in medical field

Mechatronic medical applications	**Disadvantages**
Robotic Surgery	Human error by surgeons; surgery is expensive; increased size of robotic system.[56]
Invasive and Precision surgery	Requires specialized training and expertise by surgeons; takes longer operative time; higher cost; limited access to operative area.[58]
Healthcare equipments	High initial cost; maintenance and repair costly; needs highly trained workers to operate.[60]
Prosthetics and Exoskeleton	Can reduce human flexibility, potentially leading to new sources of musculoskeletal disorders and accidents; may not be suitable for all individuals.[61]
Diagnostic imaging((CT, MRI, Ultrasound)	CT: Poor resolution; risk due to ionizing radiation; Sensitive to acute hemorrhage. MRI: Very expensive; no electronic equipments should be kept in the room as strong magnetic fields used in this technique can damage them.

	Ultrasound: Not suitable for deep body scan; Not suitable for organs obscured by bowel.[61]
3-D printing	Restricted range of materials suitable for 3D printing in healthcare;requires thorough validation and testing for ensuring 3D-printed medical products' safety and efficacy standards; maintaining consistency in quality of 3D-printed medical products is challenging.[62]
Drug delivery	Requires advanced technology/manufacturing process; high cost; requirement of further scientific trials before wide implementation of drug.[63]
Research and Diagnosing	Overreliance leads to decreased clinical judgment; increased risk of errors and system failures.[64]

4. Conclusions:

The future of mechatronics engineering in medical field is highly bright and promising, due to the fact that technology is continuing to advancement and evolving. Mechatronics can help in enabling the development of most intelligent, adaptive, and personalized devices and systems meeting the diverse and dynamic requirements of patients and healthcare providers/doctors. Mechatronics can help in fostering the integration and collaboration of different branches, disciplines and domains, like biology, medicine, and engineering, creating holistic and person-centered solutions for healthcare. Mechatronics can lead to revolutionizing the healthcare industry by transforming the method of diagnosing, treatment, monitoring, and rehabilitating patients, and finally, by improvement in the health and well-being of humanity.

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