International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 12 | Dec 2025 www.irjet.net p-ISSN: 2395-0072

Expanding the Role of Robotics in Healthcare: Transformation with Future Potential

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Abstract - *Healthcare has been identified as one of the key application areas for robotics. The introduction of robotics in health care has significantly augmented the safety and quality of health management systems compared to manual systems due to healthcare digitization. Robots not only help physicians and medical staff to carry out complex and precise tasks but also lower their workload thus improving the efficiency of the overall healthcare facilities. Classification of health care robots is only done using application based categories to fit every aspect of hospital services ranging from cleaning robots to highly sophisticated surgical robots. The applications of robotics and automation in healthcare and allied areas are increasing day by day. This paper tries to analysis the expanding role of robotics in health care sector from hospital management system to surgery. The paper also tries to represent an overview about the pioneering robotic inventions for different types of uses including health care sector. The main aim of this paper is to focus on the potential benefits of integrating robotics in health care sector along with the promising futures such as next-generation surgical robots, intelligent rehabilitation and assistive robotics, hospital automation and logistics etc. However, there are challenges and roadblocks also to incorporate robotics in healthcare which includes not only high initial cost and maintenance, but also ethical and legal concerns with irreplaceable human oversight. Research works related to robotics with security concerns and ethical issues are still in an infant stage.*

***Key Words*: robotics, invention, healthcare, surgical robot, hospital automation.**

1. INTRODUCTION

Robotics is a cross disciplinary field of computer science and engineering. It deals with design, construction, operation and usage of robots. Robotics is applied to design machines to help and assist human to reduce workload and for greater safety. Robotics merges various fields of engineering such as mechanical engineering, electrical engineering, computer engineering, control engineering etc and mathematics. Today, robotics has a wide range of applications in electronics industries, food processing industries, automobile industries, health care sector, defence sector etc for the welfare of human society. In industrial sectors, robots are used in order to make production lines more efficient and for time saving as robots can perform more accurately with high quality work. Today, most of the robots are used in the applications of manufacturing processes, it is expected that robots will be extensively used in applications such as construction works, healthcare, space exploration, etc. in near future.

1.1 PIONEERING ROBOTIC INVENTIONS

Assimov's Three Laws of Robotics: In 1942, Issac Assimov gave his Three Laws of Robotics which provided moral guidelines of how a robot should behave and highlighted the importance of human safety in robotics. These laws still hold value in today's world for safety and ethics in robotics.

Unimate: In 1956, George Devol and Joseph Engelberger developed The Unimate, the first-ever industrial robot. It handled basic tasks like material handling and assembly and it was used for welding operations in a General Motors factory from 1961.The Unimate is recognized as the starting point of robotics in industrial settings, creating goals for workplace automation.

Shakey: Stanford Research Institute (SRI) developed Shakey from 1966 to 1972. It was the first robot that could move and make decisions and reason about its own decisions based on its surroundings. Shakey was capable of navigating through various environment using sensors, cameras, and motors, perform tasks and make decisions autonomously. It was a crucial step in the development of robots with cognitive abilities and AI-driven decision-making.

Stanford Arm: The Stanford Arm was developed by James K. Salisbury in 1969. It was one of the earliest robotic arms capable of performing tasks autonomously. Stanford Arm paved the way for robotic arms to be used for industrial and medical use. These arms decreased the load on humans from doing physically tiring or precise work.

PUMA 560: In the early 1980s, the PUMA 560 robotic system was employed in surgical operations to assist in needle guidance during brain surgery. This represented the inception of robotics in medical field, highlighting the precision and possible advantages of robot-assisted surgeries for intricate medical procedures.

Honda E0 and Asimo: Honda started studying humanoid robots in 1990, which resulted in the development of the E0, a walking and balancing robot prototype. This advancement laid the foundation for later humanoid robots like ASIMO in

2000 by advancing the development of robots that could imitate human movements and behaviors.

IBM Deep Blue: In 1997, IBM's Deep Blue computer system defeated Garry Kasparov, the international chess champion. Although not an actual robot, Deep Blue's breakthrough marked a huge development in artificial intelligence and computer power, demonstrating that machines may surpass humans in some cognitive tasks.

Sony Aibo: In 1999, Sony introduced Aibo, an intelligent robotic dog that could interact with its surroundings, recognize commands, and show emotions. Aibo was among the first commercial robots developed for companionship and amusement, demonstrating robots' ability to function as emotional and interactive companions in everyday life.

Roomba: As one of the first widely successful consumer robots that can navigate a home floor autonomously to clean dust and debris, the "Roomba 2002" refers to the first commercially available Roomba robotic vacuum cleaner, which was introduced by iRobot in September 2002. It is essentially the modern concept of a robotic vacuum cleaner, using sensors to avoid obstacles and fall down stairs.

NASA's Spirit and Opportunity: NASA sent Spirit and Opportunity, twin rovers, in 2003 to explore Mars and assess its potential for supporting history. Studying the Mars surface and features, looking for traces of water, and accepting the elements of basic and important processes in allure annals were the goals of the expedition. Both landed for their missions in 2004, and in spite of the difficulties, the rovers lived significantly longer than they had anticipated. While Opportunity maintained its allure responsibility until June 10, 2018, discovering groundbreaking evidence of Mars' diluted past and establishing the habit for future surveys, Spirit was alive just until March 22, 2010.

Softbank Pepper: Soft Bank introduced Pepper, a humanoid robot made to engage and naturally connect with people, in 2014. Pepper was one of the first robots designed specifically to improve human-robot interaction since it was meant to comprehend human emotions through speech, tone of voice, and facial expressions. Pepper's strong sensors, cameras, and microphones allow it to recognize emotional cues and react accordingly, providing a more customized experience. Additionally, it has a touch screen on its chest that provides new ways to interact and access data. Pepper was created for both personal and professional usage, and it has been widely used in settings like retail stores, customer service positions, and educational institutions. A major turning point in robotics, Pepper's debut demonstrated how robots might not only assist with tasks but also interact emotionally with humans.

Tesla Autopilot 7.0: Tesla's software version 7.0 marked a significant advancement in advanced driver-assistance systems (ADAS) with the release of Autopilot in October 2015. This invention aimed to improve driving convenience and safety using a number of clever features. Traffic-Aware Cruise Control (TACC) maintained a safe following distance from other vehicles, Navigate guided the vehicle toward highway interchanges and exits, and Auto Park allowed the car to automatically navigate into parking spaces and Auto steer kept it in clearly marked lanes. Tesla established the foundation for Autopilot by allowing consumers to pre-purchase the device as early as October 2014. The first version of Autopilot was eventually made available in October 2015, a year later. The software is always getting better thanks to Tesla's creative use of over-the-air updates; new features and enhancements are frequently added every few weeks. Tesla demonstrated its goal of integrating cutting-edge technology into everyday driving and accelerating the shift to fully autonomous vehicles with the introduction of Auto pilot [1].

1.2 Different invented robots

Healthcare robots are designed to operate in medical environments, supporting patients and supporting healthcare professionals. They range from mobile robots that deliver medications and linens to operating rooms, to rehabilitation devices that help patients regain mobility after injury or illness. Surgical robots such as the *da Vinci* system allow for minimally invasive procedures with high precision, reducing patient recovery time and risk.

Home and domestic robots have brought automation into everyday life, helping with household chores and personal convenience. Common examples include robotic vacuum cleaners like the *Roomba*, robotic lawn mowers, and pool cleaners, all designed to reduce the burden of repetitive cleaning tasks. More advanced systems integrate with voice assistants like Alexa or Google Home, enabling voice-controlled automation for lighting, security, and appliances.

Industrial and manufacturing robots are among the most well-known in the robotics sector. Working in assembly lines worldwide, these machines handle welding, painting, material transport, and packaging with speed and accuracy. They can work continuously without fatigue, leading to higher productivity and reduced costs. In the automotive industry, robotic arms assemble car components with millimeter precision, while in electronics, they place tiny components on circuit boards faster than any human could. Their reliability and efficiency have made them the backbone of modern production facilities.

Logistics robots play a critical role in supply chain management by automating the movement of goods in warehouses, factories, and distribution centers. These robots collect products from shelves, stack them in storage, and prepare them for shipment. Companies like Amazon use fleets of autonomous mobile robots to quickly locate and transport items.

Telepresence robots are mobile units equipped with cameras, microphones, and screens that allow users to be in a remote location without physically being present. They can be controlled over the internet, enabling doctors to examine patients in distant clinics, employees to attend meetings from home, or family members to visit loved ones in hospitals. By providing real-time visual and audio communication, telepresence robots reduce travel costs and make remote interactions more personal.

Cyborgs, exoskeletons, and wearable robots are used to enhance or restore human physical capabilities. Exoskeleton suits, for example, can help paraplegic patients walk again or allow factory workers to lift heavy loads without strain. In the military, wearable robotics can improve soldier endurance by carrying gear or providing extra strength in combat situations. These devices combine mechanical engineering with biomechanics, creating a powerful fusion of human control and robotic assistance.

Humanoid robots are built to resemble and behave like humans. They may have realistic facial features, expressive gestures, and the ability to engage in conversation. While they often serve as research tools for studying human-robot interaction, they are also used in customer service, education, and public demonstrations. An example of a humanoid robot is *Sophia*, an AI powered robot known for its human like appearance, its ability to show facial expressions, and interact with a person or a crowd.

Military robots perform tasks in environments too dangerous for soldiers. Bomb disposal units detect and neutralize explosives, reconnaissance robots gather intelligence on enemy movements, and supply robots deliver ammunition and food to frontline troops. Drones provide aerial surveillance and precision strikes at enemy territory. The primary function of these robots is to reduce human risk in combat and enhance operational efficiency.

Autonomous vehicles include self-driving cars, pilotless drones, and underwater exploration craft. Using sensors, GPS, and AI, they navigate without human control, making them suitable for transportation, delivery, and environmental monitoring. Self-driving cars aim to reduce traffic accidents and congestion, while autonomous submarines explore ocean depths.

Space exploration robots operate in environments too hostile for humans, such as the surfaces of other planets or the vacuum of space. Rovers like *Sojourner* and *Perseverance* explore Mars, collecting data and conducting experiments. Robotic spacecraft like *Voyager* and *Cassini* investigate outer planets. These robots are critical to advancing our understanding of the universe.

Entertainment robots are designed for leisure, education, and creative applications. They appear as robotic pets, interactive toys, animatronics in theme parks, or installations in art exhibits. They can engage children in learning activities, entertain audiences with performances, or create immersive experiences in gaming.

Environmental and alternative energy robots focus on sustainability, often powered by renewable sources like solar, wind, or wave energy. They may monitor pollution levels, clean up oceans, or manage agricultural tasks in remote areas. Solar-powered trash collectors, for example, operate indefinitely without needing fuel. These robots help reduce environmental impact while performing essential conservation work.

Swarm and microbots are small, often simple robots that work together to complete a task. In swarm robotics, hundreds or thousands of tiny units coordinate to compensate low computing power, making them effective for search and rescue, environmental sampling, and exploring dangerous areas. Microbots are also being researched for medical applications, such as delivering drugs inside the human body or performing microsurgery.

Robotic networks allow machines to share data and learn from one another's experiences. In a connected warehouse, for example, if one robot finds a faster route to a product location, it can update the network so all robots use the same path. This collaborative intelligence increases efficiency and adaptability in dynamic environments.

Modular robotics involves building robots from multiple interchangeable units that can rearrange into different configurations. In space exploration, modular robots could reconfigure themselves to adapt to varying terrains and mission requirements, providing flexibility without sending multiple specialized machines[1], [2], [3].

2. Pioneering robotic inventions in healthcare sector PUMA 560

The Programmable Universal Machine for Assembly (PUMA) 560 is often acknowledged as the first robot utilized in a medical procedure. Created in the late 1970s by Unimation with contributions from Victor Scheinman, this robotic arm was initially intended for industrial use, but its accuracy soon drew attention from the medical field. In 1985, it was employed to conduct a stereotactic brain biopsy guided by computed tomography (CT), representing the first recorded instance of a robot being used in surgery. The PUMA 560 offered sub-millimeter precision in the positioning of surgical tools, minimizing the potential for human error during intricate brain operations. Although it seems basic in comparison to modern technology, it demonstrated that robotic systems could help surgeons achieve levels of accuracy that surpass manual techniques[4], [5].

Cyber dyne HAL (Hybrid Assistive Limb)

The Cyber dyne HAL, created in Japan, is a wearable robotic exoskeleton aimed at improving mobility for individuals with lower-limb disabilities resulting from spinal cord injuries,

strokes, or neuromuscular conditions. HAL operates by detecting subtle bioelectrical signals produced when the brain sends movement instructions to the muscles. These signals are gathered through sensors placed on the skin and converted into mechanical support, allowing the user to stand or walk with greater ease. In contrast to passive assistive devices, HAL actively enhances the movements the user intends to make, facilitating rehabilitation by promoting the natural recovery of the body's neural pathways. It is utilized in hospitals and rehabilitation facilities around the globe, demonstrating how robotics can aid in restoring physical independence instead of merely compensating for lost abilities[5], [6].

Da Vinci Surgical System

Launched in 2000 by Intuitive Surgical, the da Vinci Surgical System transformed minimally invasive surgical techniques. It features robotic arms that hold surgical tools and a high-definition 3D visual system, all operated by a surgeon seated at a console. The system converts the surgeon's hand movements into precise micro-movements, thereby eliminating tremors and allowing for exceedingly delicate procedures through small incisions. Surgical operations like prostatectomy, cardiac valve repair, and gynecological procedures experience benefits such as reduced blood loss, diminished postoperative discomfort, shorter hospital stays, and quicker recovery times. The da Vinci system continues to be one of the most prevalent and sophisticated platforms for surgical robotics, illustrating how machines can enhance human skills while maintaining the surgeon's control[5], [7], [8].

Medtronic's Hugo Robotic-Assisted Surgery (RAS) System

Hugo, created by Medtronic, represents the newest generation of robotic-assisted surgical systems. Engineered to rival current platforms like da Vinci, Hugo features modular robotic arms, superior imaging, and enhanced ergonomic control. In contrast to older systems, Hugo is built to be more portable and affordable, broadening access to robotic surgery for a greater number of hospitals globally. It incorporates cloud-based analytics and AI technologies to gather surgical performance data, assisting surgeons in honing their techniques. Hugo accommodates a range of minimally invasive procedures, aiming to enhance patient outcomes while tackling cost and usability challenges that restricted previous robotic surgery technologies[5], [9].

3. USE CASES OF ROBOTICS IN HEALTHCARE

Surgical Robotics

Robot-assisted surgeries have revolutionized operating rooms around the world by providing unparalleled accuracy, adaptability, and control. Systems like the da Vinci Surgical System and Medtronic Hugo allow surgeons to perform intricate, minimally invasive procedures through small incisions, reducing damage to the body. With robotic arms controlled from a console, surgeons can carry out precise movements, eliminating hand tremors, accessing hard-to-reach areas, and benefiting from enhanced visualization thanks to high-definition 3D cameras. These advantages lead to shorter hospital stays, reduced postoperative discomfort, and faster recovery for patients. Surgical robotics is widely utilized in fields such as cardiothoracic surgery, urology, gynecology, and even microsurgery, where precision at the millimeter level is crucial[10], [11], [12], [13].

Rehabilitation Robotics

Rehabilitation robots help individuals regain physical abilities after experiencing a stroke, spinal cord injury, or other debilitating conditions. Robotic gait trainers, such as Loomed, guide patients through consistent and precise walking patterns that promote neuromuscular recovery and the relearning process. These devices provide a level of therapy intensity that would be challenging for therapists to sustain manually, enabling patients to progress more quickly and reduce the risk of long-term disability[10], [11], [12], [13].

Tele presence and Remote Monitoring

Tele presence robots allow medical professionals and specialists to connect with patients from any location worldwide. Robots like Double—Autonomous Two-Wheel Video Conferencing Robot equipped with cameras, microphones, and touch-sensitive displays permit doctors to virtually visit hospitals, engage in real-time conversations with patients, and supervise local medical teams. This technology provides specialist healthcare to underserved regions, reduces the need for patient relocations, and proved to be particularly important during the COVID-19 pandemic, as reducing face-to-face interactions helped manage the spread of infection. These robots can also provide virtual presence of family members to the patients who are far from home or are kept in isolation. Examples include UBBO, Girraff[10].

Transportation and Logistics

Autonomous wheeled robots are increasingly utilized in hospitals to handle internal transport duties, such as delivering medications, medical records, surgical instruments, and meal trays. These robots can navigate hallways, operate elevators, and maneuver around obstacles to ensure timely deliveries without needing direct human involvement. This reduces the burden on staff, prevents delays in vital treatments, and lowers the risk of contamination of goods. They are capable of working continuously, providing uninterrupted service in a busy healthcare environment. Notable examples include the TUG robot, which is already in use in Norway, along with those from Omron and Robot nik RB1[10], [11], [13].

Medical Training and Simulation

Robotics-based simulation systems offer medical trainees a highly realistic and safe setting to practice complex surgical techniques. These simulators replicate how human tissue responds through haptic feedback and virtual anatomical models, allowing inexperienced doctors to develop their skills before working on real patients. Robotic training tools can simulate rare surgical complications, helping surgeons to prepare for unexpected scenarios. This approach ensures that professionals receive thorough training, reduces the likelihood of errors, and improves overall patient safety. An example of this is the BirthSIM birth simulator created by Laerdal Medical, which is utilized at the University Hospital in San Antonio, Texas, and simulates uterine contractions and the mother's voluntary efforts during childbirth[10].

Cleaning and Disinfection

Hospitals utilize autonomous robots equipped with UV-C light sources or hydrogen peroxide vapor systems to disinfect patient rooms, operating theaters, and hallways. These robots are effective at eliminating bacteria, viruses, and fungi on surfaces and in the air, outperforming traditional cleaning methods. They operate independently, ensuring consistent sterilization practices, and have proven valuable during emergencies like COVID-19, when preventing healthcare-associated infections was crucial. Some examples of these cleaning robots include Xanax and Tru-D[10], [11].

Patient Care and Nursing

Robots assist nurses with demanding or repetitive tasks such as moving patients between beds, measuring vital signs, or administering medications. These systems free up nurses' hands, reduce physical strain, and ensure consistent care. Certain robots can interact with patients, remind them about medication schedules, or even provide companionship, helping to address nurse shortages while maintaining patient engagement and comfort. Examples of such robots include PARO, NAO, and Bandit[10], [12], [13].

Dentistry

The use of robotics in dentistry enhances precision in various procedures, including the placement of dental implants, orthodontic treatments, and root canals. Computers are capable of planning and directing drills by utilizing 3D scans of the patient's oral cavity, ensuring perfect alignment and minimizing the risk of nerve injury. These robotic systems facilitate shorter treatment times, decrease the likelihood of complications, and contribute to better long-term outcomes. Certain robotic dental systems can even perform semi-autonomous tooth preparation while still being overseen by a dentist. Notable examples of these systems include YOMI, Yakebot, and SDI[10].

Hospital Housekeeping

Robots designed for service help housekeeping personnel by autonomously cleaning floors, collecting laundry, and disposing of medical waste. They uphold stringent hygiene standards, especially in vital areas like intensive care units, while reducing the risk of contamination for staff. These robots can function continuously without fatigue, making them the ideal solution for expansive hospitals where constant cleanliness is essential for controlling infections[10], [11].

Prosthetics

Advancements in robotics have resulted in remarkable innovations in bionic prosthetic limbs, enabling amputees to achieve more natural movement and dexterity. Wearable exoskeletons, like Cyber dyne HAL, can detect faint bioelectrical signals from the user's muscles or nerves, providing powered assistance to help regain the ability to walk and increase strength. State-of-the-art prosthetics are equipped with sensors that can pick up on muscle activity or even direct nerve impulses, allowing users to control robotic arms or legs in a natural manner. Some of these devices now include sensory feedback capabilities, helping users to perceive pressure or texture, which improves balance, grip control, and overall quality of life[12].

Behavioural Therapy

Social robots such as NAO and Kas par are being used to engage with children who have autism spectrum disorder or other developmental challenges. These robots provide consistent, noncritical interactions, allowing children to practice social signals, communication skills, and recognizing emotions. Additionally, the robots can be programmed to adjust their behavior based on therapy results, making them a valuable supplement to human-led interventions[12].

Diagnosis, Assessment, and Lab Automation

Robotic systems streamline complex laboratory tasks such as preparing slides, processing blood samples, and conducting high-volume tests. This accelerates the diagnostic procedure, increases uniformity, and reduces the possibility of human error. Pharmacy automation devices can accurately package and distribute medications, ensuring patients receive the correct prescriptions while allowing pharmacists to focus on clinical duties[11], [12].

Emergency Response

Robots are increasingly utilized in emergency scenarios such as natural disasters, hospital crises, or mass-casualty incidents. Drones and mobile robots are capable of delivering medical supplies, locating survivors, and providing real-time situational updates. Certain robots can perform CPR or provide basic first aid, initiating essential care prior to the arrival of human responders[12].

Sterilization and Packaging

Robots in sterile processing centers clean, package, and sort surgical equipment. These machines deliver surgical tools that are consistently sterilized, minimizing contamination risks and removing the need for manual labor. The automation of packaging also speeds up the turnaround time for surgical instruments, allowing hospitals to handle a greater volume of procedures efficiently[11].

Hospital Reception

Reception robots enhance the patient experience by greeting patients, completing check-ins, verifying records, and guiding them to their respective locations. They reduce waiting times, improve service efficiency, and allow administrative personnel to concentrate on more intricate tasks. Featuring AI technology, they can handle conversations in multiple languages, address frequently asked questions, and even provide health screenings in the waiting area[14].

4. POTENTIAL BENEFITS OF ROBOTICS

Enhanced Surgical Precision: Robotic-assisted systems allow surgeons to perform delicate operations with unmatched accuracy. High-definition 3D visualization and tremor-free robotic arms reduce surgical errors, minimize blood loss, and lead to faster patient recovery.

Minimally Invasive Procedures: Robots enable surgeries through very small incisions, reducing trauma to the body. Patients experience shorter hospital stays, less postoperative pain, and lower risk of infection.

Improved Efficiency in Hospitals: Autonomous robots transport medicines, surgical instruments, and supplies, streamlining hospital logistics. Laboratory robots process diagnostic tests rapidly and with minimal error, reducing delays in treatment.

Personalized and Consistent Rehabilitation: Robotic exoskeletons and gait trainers deliver intensive therapy tailored to each patient's recovery progress. These systems provide repetitive, precise movements that therapists cannot sustain manually, accelerating healing.

Increased Safety for Healthcare Workers: Robots take on hazardous tasks such as disinfecting rooms, handling contaminated waste, or delivering supplies to isolation wards. This reduces staff exposure to infectious diseases and physically strenuous labor.

Better Access to Specialized Care: Tele presence robots allow doctors to consult with and monitor patients remotely, even in rural or underserved areas. Robotic platforms combined with AI diagnostics ensure timely detection and intervention for critical conditions.

Reduction in Human Error: Robots in pharmacy automation, diagnostics, and sterilization deliver consistent, high-precision results. This minimizes the likelihood of incorrect medication, inaccurate tests, or poorly sterilized instruments.

Support for Nursing and Patient Care: Robots assist with lifting patients, delivering meals or medication, and monitoring vital signs. This reduces nurse workload and ensures patients receive round-the-clock support.

Advances in Prosthetics and Assistive Devices: Robotic prosthetic limbs restore natural movement using sensors that detect muscle or nerve impulses. Some advanced devices provide sensory feedback, improving balance, grip control, and overall quality of life.

Lower Long-Term Healthcare Costs: By improving efficiency, reducing hospital stays, and minimizing complications, robotics helps control overall healthcare expenses. Hospitals can handle higher patient volumes without compromising quality.

Consistency and Reliability: Unlike human workers, robots do not suffer from fatigue, distraction, or performance variation. They can operate continuously, maintaining strict quality and hygiene standards around the clock [10], [11], [12], [15].

5. PROMISING FUTURE OF ROBOTICS

Robotics is entering a new phase where machines have evolved from mere programmable tools to intelligent partners that can perceive, learn, and adapt. Breakthroughs in artificial intelligence, machine learning, cloud computing, and advanced sensors are allowing robots to function autonomously in dynamic and unpredictable settings. In contrast to previous generations of robots that were limited to monotonous, structured tasks, the next wave of systems will work closely with humans, effortlessly transitioning between guidance and autonomy. Future robots are expected to be smaller, more affordable, and versatile, becoming integrated into daily life and various industries well beyond just factory environments. Robotics is anticipated to significantly impact transportation, manufacturing, space exploration, agriculture, and disaster response. Additionally, the interaction between humans and robots is being revolutionized through advancements in natural language processing, computer vision, and haptic feedback, making robots easier to use and more trustworthy as collaborators.

In the healthcare industry, the prospects appear promising, and it will undoubtedly gain from emerging robotic technologies. The combination of robotics with artificial intelligence, machine learning, cloud computing, and natural language processing will transform patient care, enhancing its personalization, efficiency, and accessibility. Future

robots will collaborate with doctors and nurses, becoming a vital component of the healthcare system. Several areas within healthcare that will significantly gain from the incorporation of robotics are highlighted below:

Next-generation surgical robots: Upcoming surgical systems will not only mimic a surgeon's manual actions but also integrate AI-driven decision support that can propose the best surgical approaches and alert surgeons to possible complications as they arise. Trials are currently underway for fully autonomous robotic surgeries, which are managed by surgeons rather than directly manipulated, focusing on less complex operations. As technology progresses, surgical robots and tele presence robots will merge to enable surgeries in distant locations where the physical presence of medical professionals may be unfeasible.

Intelligent rehabilitation and assistive robotics: Robotic therapy systems are set to develop into more lightweight, adaptable, and budget-friendly options for personal use at home. They will utilize neuro feedback along with AI-powered motion analysis to constantly tailor therapy programs for individual patients, thereby speeding up recovery from strokes, spinal injuries, and degenerative ailments. Rather than being restricted to specialized rehabilitation facilities, these systems could become as prevalent as home fitness machines.

Hospital automation and logistics: Autonomous delivery robots will be completely integrated with hospital management systems, facilitating the seamless movement of medicines and equipment without the need for human oversight. These robots are not limited by physical constraints, enabling them to transport heavy equipment that would typically require numerous personnel. In emergency situations, robots can quickly deliver medications to doctors. Because of this, logistics is the most straightforward, safest, and most vital area that has to be fully automated with robots, freeing up human talent for other areas which are tougher to fully automate or require human input for safety and improved patient feedback.

Personalized patient care and nursing support: Advancements in nursing robots will integrate emotional awareness, voice recognition, and biometric tracking, allowing them to deliver not only physical support but also emotional and psychological assistance. They will continuously monitor patient health, notifying staff in case of emergencies and supplying checkup data to facilitate shorter hospital stays. The 24/7 monitoring capability is particularly appealing in robotic nursing since human nurses need to take breaks and work in shifts. While this future holds great promise, transitioning to fully robotic care is challenging because patients typically prefer human interaction over robotic care. Therefore, fostering effective human-robot interaction is crucial, as the nursing field is likely to adopt a hybrid model.

AI-driven diagnostics and laboratory robotics: The upcoming generation of diagnostic robots will combine imaging, bio sensing, and automated laboratory testing to identify diseases at an earlier stage than existing systems. By analyzing massive datasets in real time, they will instantly recognize laboratory tests to deliver accurate results. There will be no delays in receiving lab reports. Furthermore, these robots will have the capability to process thousands of tests, making laboratory testing instant in any location worldwide. This advancement will also enable laboratory facilities to be established in places where it was previously unfeasible.

Expanded telemedicine through robotic presence: Tele presence robots will progress from basic video devices to interactive diagnostic units fitted with sophisticated sensors for monitoring vital signs and performing minor procedures. In remote and underserved regions, these robots will serve as "virtual clinics", providing access to expert medical care without the need for travel, thus helping to address global healthcare disparities.

Hygiene, sterilization, and infection control: Autonomous disinfection robots will utilize AI-based mapping and pathogen identification to focus on high-risk areas rather than applying disinfectants uniformly. Future sterilization robots are set to track microbial levels in real time, ensuring that hospitals comply with strict infection control standards while avoiding excessive use of cleaning agents. By increasing the role of robots in disinfection and decreasing human involvement, there will be a lower risk of illness from exposure and the completion of tasks that can be hazardous for people. This technology has already been implemented during the COVID-19 pandemic and is expected to be beneficial for future outbreaks.

Advanced prosthetics and bio hybrid robots: Robotic prosthetics are expected to become more realistic and energy-efficient, utilizing direct brain-machine interfaces for more intuitive control. Some of these may also meld with biological tissue, creating hybrid systems that can grow, heal, and adapt similarly to natural limbs. Additionally, individuals without disabilities might voluntarily integrate robotic devices into their bodies to enhance their capabilities for specific tasks. This type of fusion between humans and robotic exoskeletons has been illustrated in popular media, such as the game Cyberpunk 2077 [2], [5], [10], [12].

6. CHALLENGES AND ROADBLOCKS

High Initial Cost and Maintenance: Robotic systems such as surgical platforms and hospital automation devices require significant investment. The cost of installation, software upgrades, and regular maintenance can be prohibitive for small or resource-limited hospitals.

Complex Training Requirements: Doctors, nurses, and technicians must undergo specialized training to operate and

maintain these systems effectively. Steep learning curves can delay adoption and affect the efficiency of early use.

Integration with Existing Healthcare Infrastructure: Many hospitals lack the IT and physical infrastructure needed to support advanced robotics. Ensuring compatibility with electronic health records (EHRs), hospital workflows, and safety protocols is challenging.

Technical Malfunctions and Downtime: Like any machine, robots can fail due to software glitches, sensor errors, or mechanical breakdowns. Such failures during critical medical procedures or logistics operations can lead to delays, complications, or patient risk.

Ethical and Legal Concerns: Questions around liability arise: Who is responsible if a robotic system makes an error — the manufacturer, the hospital, or the operator? Regulatory frameworks are still evolving to address these complex issues.

Limited Autonomy and Decision-Making: Current robots rely heavily on human supervision and cannot make complex medical decisions independently. Fully autonomous systems raise safety and accountability concerns, slowing regulatory approval.

Resistance from Medical Staff and Patients: Some healthcare professionals fear that robots could replace their roles or undermine their expertise. Patients may feel uneasy or lack trust when treated by machines rather than humans.
Cyber security Risks: Network-connected robots can be vulnerable to hacking, data theft, or malicious interference. Securing patient data and ensuring uninterrupted operation requires strong cyber security measures.

Power and Space Constraints: Large robotic systems, especially in surgery, require dedicated operating rooms, special power setups, and controlled environments. Retrofitting older hospital facilities to meet these requirements is often costly and difficult.

Slow Regulatory Approval and Compliance: Medical robots must meet stringent safety and performance standards before being deployed. The lengthy approval process slows innovation and delays the availability of advanced systems.
Limited Accessibility in Developing Regions: Due to high cost and infrastructure requirements, cutting-edge robotic systems are concentrated in wealthier nations and urban hospitals. Rural and low-income regions still lack access to these technologies, increasing healthcare inequality.

Ongoing Need for Human Oversight: Robots cannot replace human judgment, empathy, or decision-making in complex care situations. Overreliance on automation without adequate human oversight could lead to safety lapses[13], [16].

7. CONCLUSION

Robotics is undoubtedly the Future of Technology. Researchers are working hard for the development of robotics not only in health care sector, but in all sectors to decrease workload and to increase safety of human beings. Advanced robots continue to be designed for an ever-expanding range of applications in the healthcare in future. Robots can perform tasks better, cheaper, and faster than humans and so they are in huge demand at various levels, which is always expected to increase in future. But it is important to keep a balance in application of robots and care should be taken regarding the employment and motivation of human resources. Research works related to robotics with security concerns and ethical issues must be carried out by the scientists and researchers.

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