

“Artificial Intelligence And Robotics In Pharmacy: A Comprehensive Review”

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Abstract

Artificial Intelligence (AI) and robotics are rapidly transforming the pharmaceutical industry, with significant potential for countries like India where healthcare access remains limited in rural areas. AI utilizes advanced algorithms to analyze large datasets, enabling faster and more accurate pattern recognition for applications ranging from disease detection to prevention and treatment. In recent years, their adoption in drug discovery, clinical trials, quality assurance, and healthcare delivery has increased considerably. [1] AI-driven approaches provide advantages such as improved patient care during clinical trials, enhanced safety with reduced infection risks, and efficient management of operational tasks. Robotics, on the other hand, is revolutionizing pharmaceutical manufacturing by increasing accuracy, productivity, and safety in processes like compounding, dispensing, and supply chain logistics. Automation has also accelerated high-throughput drug screening, reducing development timelines while ensuring stringent quality control. Despite these advancements, several challenges remain. [2] High initial costs, shortage of skilled professionals, data security concerns, and workforce adaptation are major barriers. Additionally, extending these technologies to underserved and industrial areas poses practical difficulties, limiting their widespread implementation.

Keywords

Artificial Intelligence (AI); Robotics; Pharmacy Automation; Drug Discovery; Clinical Trials; Pharmaceutical Manufacturing; Quality Control; Supply Chain Management; Personalized Medicine; Healthcare Innovation; Automation in Pharmacy; Digital Health; Pharmaceutical Industry; India.

Robotics in Pharmacy

Robotics has emerged as a powerful tool in the pharmaceutical industry, bringing automation, precision, and efficiency to various processes. By reducing human error and improving accuracy, robotics ensures greater safety in drug preparation, dispensing, and distribution. The role of robotics extends across hospital, retail, and industrial pharmacy, reshaping traditional practices and supporting pharmacists in delivering better healthcare outcomes. [3]

1. Automated Dispensing Systems

- Widely used in hospital and community pharmacies.
- Robots can accurately select, count, and label medications.
- Reduces dispensing errors and waiting time for patients.
- Example: Automated storage and retrieval systems (ASRS).

2. Compounding and Sterile Preparation

- Robots are used in the preparation of intravenous (IV) admixtures and cytotoxic drugs.
- Provides aseptic conditions, minimizes contamination, and ensures correct dosing.
- Example: RIVA™ (Robotic IV Automation) system.

3. Pharmaceutical Manufacturing

- Robotics improves precision and efficiency in drug production.
- Tasks such as tablet sorting, packaging, labeling, and inspection are automated.
- Enhances product quality, consistency, and compliance with Good Manufacturing Practices (GMP).

4. Supply Chain and Logistics

- Robotic arms and automated guided vehicles (AGVs) manage inventory, packaging, and warehouse operations.
- Drones are increasingly explored for medicine delivery in remote areas.
- Improves supply chain traceability and reduces labor dependency.

5. Patient Care and Service

- Robotic kiosks in retail pharmacies assist patients in medication dispensing.
- Humanoid robots and AI-driven assistants can provide counseling and medication reminders.
- Enhances patient satisfaction and adherence.

Robots

Robots are specialized automated machines designed to perform pharmacy-related tasks with high accuracy, speed, and consistency. Their integration into pharmaceutical practice has minimized human error, improved safety, and optimized workflow. Different types of robots are now being deployed across hospital, retail, and industrial pharmacy settings.



Fig. 1 Dispensing Robot [4]

1. Dispensing Robots

- Designed for hospital and community pharmacies.
- Select, count, label, and dispense medications.
- Reduce prescription errors and waiting times.
- Examples: PillPick™, ScriptPro®, ROWA® dispensing robots.

2. Compounding Robots

- Prepare sterile and hazardous medications such as IV admixtures, chemotherapy, and parenteral nutrition.
- Ensure aseptic conditions, precise dosing, and reduced risk of contamination.
- Example: RIVA™ (Robotic IV Automation).



Fig. 2 RIVA™ (Robotic IV Automation) [5]

3. Packaging and Labeling Robots

- Handle blister packing, bottle filling, and labeling of medicines.
- Provide uniformity, reduce manual workload, and improve compliance with quality standards.



Fig. 3 Packaging and Labeling Robots [6]

4. Industrial Manufacturing Robots

- Used in large-scale pharmaceutical production.
- Perform tasks like tablet pressing, coating, inspection, and sorting.
- Enhance productivity and maintain GMP (Good Manufacturing Practice).

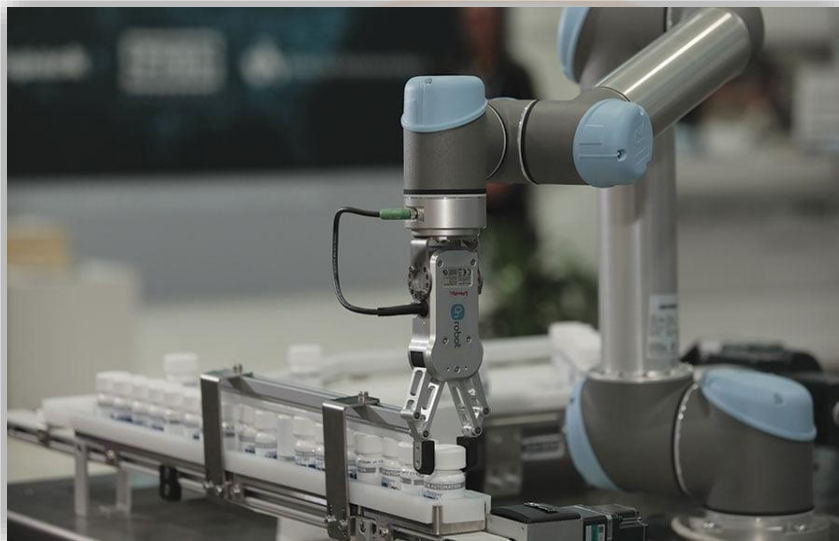


Fig. 4 Industrial Manufacturing Robots [7]

5. Service and Delivery Robots

- Assist in supply chain operations including warehouse management, inventory handling, and medicine delivery.
- Autonomous mobile robots (AMRs) and drones deliver medicines to remote or emergency areas.



Fig. 5 Service and Delivery Robots [8]

6. Patient Assistance Robots

- Provide direct interaction with patients in retail settings.
- Humanoid robots can offer basic counseling, medication reminders, and adherence monitoring.
- Example: AI-powered humanoid robots used in smart pharmacies.

Robotic Process Automation (RPA)

Robotic Process Automation (RPA) is a software-based automation technology that mimics routine back-office tasks performed by humans, such as extracting data, filling forms, and transferring files. In healthcare, RPA is increasingly integrated with Artificial Intelligence (AI) to support diagnosis, treatment, patient engagement, adherence monitoring, and administrative applications. [9]

According to a study by Grand View Research, the global pharmaceutical robotics market is projected to reach USD 357.9 million by 2030, growing at a CAGR of 9.2% from 2022 to 2030. This growth is largely driven by the ability of automated systems to handle repetitive tasks rapidly, accurately, and safely.

The COVID-19 pandemic significantly accelerated the adoption of pharmaceutical robotics worldwide. Robots played a critical role in processing diagnostic test samples, manufacturing testing kits, and producing protective equipment such as masks and gloves. Data from the Robotic Industries Association (RIA) revealed that orders for robots from North American life sciences companies increased by 69% in 2020 compared to 2019, underscoring the rising demand for automation in the pharmaceutical sector.

Traditionally, robots in the pharmaceutical industry have been designed primarily for large-scale industrial applications. They are now widely used in drug packaging, research laboratories, cleanroom maintenance, and manufacturing processes. With advancements in design and functionality, robots are becoming

increasingly versatile, reliable, and efficient, positioning them as a cornerstone of modern pharmaceutical operations.

Health Status Monitoring and Assistance [11]

Robots equipped with sensors and AI capabilities can continuously monitor patients' health and provide timely assistance. In emergencies, these robots can alert caregivers or healthcare professionals while tracking vital signs and detecting changes in health indicators.[10] Beyond monitoring, they also assist with daily activities such as meal preparation, mobility support, and fall detection. These functions enhance patients' overall well-being and help them maintain independence for a longer period.

Physical Rehabilitation and Therapy [12]

Certain home robots are specifically designed to support physical therapy and rehabilitation. They guide patients through prescribed exercises, assess progress, and relay data back to healthcare providers. For example, **Catalia Health's Mabú robot** engages patients in conversations to improve health outcomes by promoting adherence to medication regimens and lifestyle changes.

Amusement Robots [13]

Amusement robots, also known as entertainment robots, are primarily intended for recreation and engagement. However, they have emerging roles in pharmaceutical and healthcare contexts, particularly in patient care, therapy, and emotional well-being.

Therapeutic and Emotional Support

Amusement robots can provide comfort to patients undergoing long-term treatments or experiencing emotional distress. **PARO**, a therapeutic robot shaped like a baby harp seal, has been widely used in dementia, autism, and mental health care to provide companionship and reduce anxiety. In pharmaceutical settings, such robots can create a calming environment for patients involved in clinical trials or undergoing therapy.

Pediatric Care and Distraction

Children often experience fear and anxiety during hospital stays or medical procedures. Amusement robots can serve as engaging companions, offering storytelling, interactive games, and imaginative play. For example, **Moxie**, a socially assistive robot, promotes children's emotional, cognitive, and social development through interactive learning activities. Integrating such robots into pediatric wards or research centers can improve the hospital experience for young patients and their families.

Rehabilitation and Therapy

Some amusement robots are adapted for rehabilitation purposes. These robots support interactive exercises, motor skill development, and cognitive training. For instance, the **Keepon robot**, initially created for autism research, has been repurposed for therapeutic applications in rehabilitation programs. Their use in clinical trials and patient-centered interventions enhances treatment engagement and outcomes.

Care Robots

Care robots—also known as assistive or social robots—are designed to support individuals with daily living activities, particularly the elderly and those with disabilities. They are increasingly connected to the pharmaceutical sector by aiding in **patient care, drug administration, and healthcare delivery**. Their role extends beyond physical assistance, as they also provide companionship, monitor health, and encourage adherence to medication schedules, thereby improving overall quality of care.

Applications of Care Robots in Pharmacy and Healthcare [14]

Improved Patient Care

Care robots are designed to provide individualized support by monitoring health indicators and facilitating communication between patients and healthcare professionals. They can also offer companionship and emotional support, which is particularly beneficial for patients living alone or undergoing long-term treatment. By integrating care robots into pharmaceutical and clinical settings, companies aim to enhance patient engagement, satisfaction, and overall well-being.

Better Medication Management

Medication adherence is a critical factor in achieving successful treatment outcomes. Care robots assist patients by reminding them to take medications on time, dispensing tablets according to prescribed schedules, and tracking adherence patterns. Advanced technologies such as speech recognition and facial identification ensure that the correct patient receives the right medication at the right time. This reduces medication errors and promotes patient safety while improving therapeutic results.

Improved Healthcare Delivery

Care robots play a significant role in advancing healthcare delivery by enabling telemedicine consultations, remote health monitoring, and patient education. Through integrated sensors, these robots can collect and share health data with medical professionals in real time. Such capabilities expand access to healthcare, particularly for patients in remote or underserved regions, as well as for individuals with mobility challenges. Pharmaceutical companies envision care robots as vital tools for bridging healthcare gaps in developing regions.

Empowerment of Healthcare Professionals

By automating routine tasks such as medication administration, patient monitoring, and record-keeping, care robots reduce the workload on healthcare staff. This not only improves workflow efficiency but also minimizes caregiver fatigue, allowing professionals to focus on complex clinical responsibilities. In pharmaceutical environments, care robots complement human expertise, contributing to the delivery of safe, high-quality patient care.

Considerations in Selecting Robots for Pharmaceutical Applications

Choosing the right robot for pharmaceutical or cleanroom applications requires careful evaluation of the operating environment and compliance with regulatory standards. Robots are classified based on the number of particles they generate during movement, which determines their suitability for cleanroom use. A major concern is the release of dust from robotic arms, end effectors, or gases emitted by hoses and belts.

Therefore, manufacturers supplying robots to the pharmaceutical, biotechnology, and medical industries must ensure their products meet stringent cleanroom certifications. Selecting appropriately certified robots is critical for maintaining sterile conditions, minimizing contamination risks, and ensuring adherence to Good Manufacturing Practices (GMP).

Robotics in Sterile Manufacturing [15]

In the pharmaceutical industry, robotics plays a crucial role in **sterile manufacturing** by ensuring contamination control, precision, and regulatory compliance. Robotic systems minimize human involvement in sensitive processes, thereby enhancing safety, accuracy, and productivity.

Aseptic Filling and Packaging

Robotics is widely used in aseptic filling and packaging to reduce contamination risks. Robotic arms with sterile end-effectors handle syringes, vials, and containers with high precision, ensuring accurate dosing and sealing. Automated systems in isolators or cleanrooms maintain sterility and regulatory standards throughout production.

Sterile Compounding and Mixing

Robotic systems support the preparation of sterile formulations, IV solutions, and customized pharmaceuticals. By automating weighing, dispensing, and mixing operations, robotics ensures accuracy, reproducibility, and minimal contamination. [16] These systems operate in controlled environments to maintain sterility and patient safety.

Sterile Filtration and Purification

In processes like filtration, chromatography, and purification, robotics ensures consistent quality and pathogen removal. Advanced robotic systems provide real-time monitoring, adjust filtration parameters, and optimize process performance, thereby improving both quality control and regulatory compliance.

Sterile Packaging and Labeling

Robotics automates packaging line operations such as handling, inspection, labeling, and sealing. Integrated vision systems and sensors enable precise product positioning, tamper-evident sealing, and defect detection. This enhances traceability, product safety, and productivity in sterile packaging.

Research and Development (R&D) [17]

Robotics is essential in drug discovery, particularly in High-Throughput Screening (HTS). Robotic systems enable millions of compounds to be tested rapidly using microplates with hundreds to thousands of wells. Combined with liquid handling systems, detectors, and data analysis software, HTS accelerates the discovery of novel drugs, antibodies, and genetic targets, while also improving understanding of biological pathways.

Conclusion

Artificial Intelligence (AI) and robotics are transforming the pharmaceutical industry by enhancing efficiency, accuracy, and patient safety across multiple domains, including drug discovery, sterile manufacturing, clinical trials, and patient care. Robotics ensures precision in manufacturing, sterile compounding, aseptic filling, packaging, and quality control, while AI facilitates data-driven decision-making, predictive analytics, and personalized medicine. Care robots and home-assistive robots improve

patient monitoring, adherence, rehabilitation, and emotional support, making healthcare more accessible and patient-centric.

Despite these advancements, challenges such as high implementation costs, technical complexity, workforce adaptation, data security, and regulatory compliance remain. In the Indian context, integrating these technologies into rural and underserved areas poses additional logistical and infrastructural challenges.

Overall, the combination of AI and robotics offers unprecedented opportunities for innovation, efficiency, and scalability in pharmaceutical operations and patient care. Strategic implementation, supported by proper training, regulatory oversight, and investment, is essential to fully realize their potential. As these technologies continue to evolve, they are expected to redefine pharmaceutical practice, enhance healthcare delivery, and improve patient outcomes on a global scale.

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