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Automation and Robotics in Pharmaceutical Industry – Review Article

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ABSTRACT
The combination of automation and robotics technology is causing a dramatic shift in the pharmaceutical sector. The abstract delves into the various aspects of automation and robotics in pharmaceutical processes, including medication research, production, distribution, and discovery. Automation has made it possible to do high-throughput screening, which has sped up the process of finding possible drug candidates and shortened the time it takes to develop new drugs. Conversely, robotics is transforming the manufacturing industry by improving accuracy, productivity, and security. Quality control is using more and more automated methods to ensure that strict regulations are followed and to reduce human mistake [1]. Furthermore, robotics and automation are essential for streamlining supply chain operations, from distribution and packaging to inventory control. In addition to streamlining processes, these technologies enhance traceability and compliance, which are essential for guaranteeing the safety of patients and the quality of products. The integration of automation and robotics offers significant advantages, but it also comes with drawbacks, including initial investment costs, technical complexity, and workforce adaptation. In addition, implementation strategies must be carefully thought out due to concerns about data security and regulatory compliance. In conclusion, the utilization of automation and robotics in the pharmaceutical industry offers unprecedented opportunities for innovation, efficiency, and scalability. However, realizing their full potential requires a strategic approach that addresses technological, regulatory, and organizational aspects to navigate the evolving landscape of pharmaceutical manufacturing and deliver [2].

I. INTRODUCTION

Automation and robots have revolutionised the pharmaceutical sector in the last few decades. This change has been driven mostly by technological breakthroughs. Automation and robots, which are frequently portrayed in futuristic settings and are typically linked with simplifying production processes, have become essential instruments in the pharmaceutical industry. Their integration has transformed the industry in a number of ways, including manufacturing, distribution, and medication discovery and development. Automation and robots have been increasingly popular in pharmaceutical operations due to the need for improved scalability, precision, and efficiency. With their unmatched accuracy, speed, and dependability, these technologies dramatically quicken research and production while reducing errors and unpredictability. Pharmaceutical corporations can now more effectively tackle complicated issues like medication repurposing and personalised therapy, as well as the expanding demands of global healthcare systems.[3] Furthermore, robotics and automation are essential for guaranteeing product quality and regulatory compliance. Pharmaceutical manufacturers can comply with strict regulatory requirements while preserving consistency and traceability throughout the production process by putting in place automated systems for quality control, batch testing, and documentation. This reduces the dangers of contamination and human mistake while simultaneously improving patient safety[4] Moreover, the pharmaceutical supply chain as a whole is included in the automation and robotics integration, going beyond the boundaries of manufacturing facilities. These solutions maximise operating efficiency, reduce waste, and enhance product traceability in a variety of applications, including distribution, packaging, and inventory management and logistics. Pharmaceutical businesses are therefore more equipped to handle the intricacies of international distribution networks and react quickly to market demands. Nevertheless , there are obstacles in the way of the pharmaceutical industry's use of automation and robots. Significant implementation challenges include high initial investment costs,

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technical complexity, and the requirement for experienced personnel. Furthermore, strategic preparation and careful thought are required due to worries about data security, regulatory compliance, and ethical ramifications. [5] Within this framework, the purpose of this study is to investigate the many aspects of automation and robotics in the pharmaceutical sector. It will explore the developments, uses, difficulties, and effects of various technologies, looking at how they may affect medication development, discovery, production, and distribution. In order to help stakeholders and decision-makers navigate this dynamic terrain, this paper analyses current trends, best practices, and new developments in order to provide insights into the changing landscape of pharmaceutical automation and robotics.[6]

ROBOTICS:

The creation and development of robots is the focus of the technological field of robotics. It is a rapidly expanding and changing field of technology since robotics is being used in more and more applications every day. It propels the creation of robots for use in a variety of settings, including factories, pharmacies, hospitals, and the pharmaceutical industry. [7,8]

ROBOTS:

A machine that can be programmed to carry out particular activities is called a robot. A robot can have one of two characteristics: it can be intelligent or not, autonomous or not. Without human assistance, autonomous robots are capable of operating, finishing tasks, and making decisions by themselves. [9, 10]

ISAAC AMINOV'S: THREE LAWS OF ROBOTICS

Science-fiction writer Isaac Aminov is credited with creating the "Three Laws of Robotics," with the addition of the "Zeroth Law," a fourth law, later. They are listed in the following order:

I. A robot cannot cause harm to a human being.
II. A robot will follow instructions given to it by humans, unless they conflict with the First Law.
III. A robot has to defend its existence if it does not violate the First or Second Laws.
IV. Humans cannot be harmed by robots.[11]

TYPES OF ROBOTS:

1. ROBOTIC ARMS OR INDUSTRIAL ROBOTS:

Robotic arms are adaptable devices that are utilised in the pharmaceutical industry to perform assembling, labeling , and picking and packing duties. These robots improve productivity and quality control in pharmaceutical production facilities by handling sensitive materials and carrying out repetitive activities with extreme precision and efficiency. [12]

[86]

2.AUTOMATED GUIDED VEHICLES (AGVS):

AGVs are autonomous mobile robots that are utilised in pharmaceutical production facilities and warehouses for material handling and transportation. These vehicles transfer equipment, completed goods, and raw materials between several places by utilising sensors and guidance systems to travel predetermined routes.[13]

[87]

3.COLLABORATIVE ROBOTS (COBOTS):

The purpose of collaborative robots is to support human workers in pharmaceutical production settings. These robots can securely perform activities like packaging, inspection, and laboratory automation in close proximity to human workers thanks to their safety measures and sensor-equipped designs.[14]

[88]

4.AUTOMATED DISPENSING SYSTEMS:

Robotic equipment called automated dispensing systems are used in pharmacies and medical facilities to precisely deliver medication and manage inventories. These systems decrease drug errors, increase the efficiency of medicine dispensing procedures, and manage a broad variety of pharmaceutical items. [15]

[89]

5.LABORATORY AUTOMATION SYSTEMS:

Robotic platforms are used in laboratory automation systems to automate a variety of laboratory tasks, such as testing, analysis, and sample preparation. Pharmaceutical research & development laboratories benefit from increased throughput, reproducibility, and precision thanks to these systems.[16]

[90]

6.HOME ROBOT:-

The functional household robot and the entertainment robot are the two categories of home robots that will be covered in this section. Regarding entertainment robots, we have distinguished between the robots that interact socially and those that interact physically, such sex robots. [17]

6.1.HOUSEHOLD ROBOTS :-

Though uncommon, household robots—which are generally made to help with household chores—have found use in the healthcare and pharmaceutical industries. These robots help the pharmaceutical business achieve its overarching objectives by participating in telemedicine, prescription administration, and patient monitoring. The pharmaceutical industry and home robots interact in the following ways.

6.1.1.TELEMEDICINE AND REMOTE CONSULTATIONS:

Patients and healthcare professionals can consult remotely thanks to household robots that are outfitted with cameras, microphones, and communication devices. From the comfort of their homes, patients can communicate with physicians or chemists about treatment programmes, prescription schedules, and any issues they may have. In addition to increasing accessibility to healthcare services, this also lessens the need for in-person visits, which is advantageous for patients who live in rural places or have mobility impairments.[18]

6.1.2.MEDICATION MANAGEMENT:

Patients can benefit from household robots' assistance in efficiently managing their meds. These robots can dispense tablets from pre-filled containers, remind patients to take their meds on time, and even track medication adherence over time. To improve medication adherence and lower the possibility of medication errors, robots such as the Pillo Health medication dispenser, for instance, employ facial recognition technology to give the appropriate pills to the correct person at the right time. [19]

6.1.3.HEALTH STATUS MONITORING AND ASSISTANCE:

With sensors and AI capabilities, certain home robots can keep an eye on patients' health and offer help when required. In the event of an emergency, these robots may notify carers or healthcare professionals and monitor vital signs and changes in health indicators. They can also help with everyday duties including meal preparation, mobility support, and fall detection, which can improve patients' general wellbeing and prolong their period of independence.[20]

6.1.4.PHYSICAL THERAPY AND REHABILITATION:

Some home robots are made to help patients with physical therapy and rehabilitation exercises. These robots evaluate patients' progress, lead patients through recommended workouts, and report back to healthcare professionals. For instance, Catalia Health's Mabu robot converses with patients to promote improved health outcomes by encouraging adherence to prescription schedules and lifestyle modifications. [21]

6.2 AMUSEMENT ROBOTS:-

Amusement robots, sometimes referred to as entertainment robots, are made to entertain and engage humans in recreational activities. Amusement robots have potential uses and links with pharmaceutical settings, especially in the areas of patient care, therapy, and well-being, even though their main goal is unrelated to the pharmaceutical sector. The pharmaceutical sector and entertainment robots interact in the following ways:

6.2.1.THERAPEUTIC AND EMOTIONAL SUPPORT:

Patients, particularly those receiving long-term therapies or facing emotional discomfort, can benefit from the therapeutic effects and emotional support that amusement robots can offer. For instance, PARO, a therapeutic robot fashioned like a young harp seal, has been utilised in medical settings to offer patients—including those suffering from dementia, autism, or mental health issues—comfort and company. Such robots can be used to make pharmaceutical settings more calming and encouraging for individuals undergoing clinical trials or therapies.[22]

6.2.2.PAEDIATRIC CARE & DISTRACTION:

During hospital stays or medical procedures, paediatric patients may find that amusement robots help reduce their dread and anxiety. These robots are soothing companions and sources of distraction for kids, engaging them in imaginative play, storytelling, or interactive games. For example, Embodied socially helpful robot Moxie encourages children's social, emotional, and cognitive development through interactive storytelling and instructional games. For young patients and their families, integrating these robots into paediatric wards or clinical research centres can improve their overall experience.[23]

6.2.3.REHABILITATION AND THERAPY:

Some amusement robots are designed to assist in physical rehabilitation and therapy sessions. These robots engage patients in interactive exercises, movement routines, or cognitive tasks to promote recovery and improve functional abilities. For example, the Keepon robot, originally developed for autism research, has been adapted for therapeutic applications, including motor skills development and rehabilitation. Incorporating such robots into pharmaceutical settings, such as clinical trials for rehabilitation therapies or patient-centered interventions, can enhance treatment outcomes and patient engagement.[24]

7.CARE ROBOTS:

Care robots, often referred to as assistive robots or social robots, are made to help people with many elements of everyday life, especially the elderly and those with impairments. Care robots have potential uses and links with the pharmaceutical sector, particularly when it comes to patient care, drug administration, and healthcare delivery, even though their main concentration is on providing care. This is how the pharmaceutical business and care robots interact:

7.1EXPECTATION:

Expectations for the integration of care robots within the pharmaceutical industry are centered around enhancing patient care, improving medication management, and optimizing healthcare delivery processes. While care robots are primarily designed to assist individuals with daily living tasks and provide companionship, their application within pharmaceutical settings holds potential for transforming patient experiences and optimizing clinical outcomes. Here are some expectations regarding the utilization of care robots in the pharmaceutical industry:

7.1.1. IMPROVED PATIENT CARE:

By offering individualized support, keeping an eye on health indicators, and easing communication between patients and medical professionals, care robots are anticipated to improve patient care. These robots can provide patients with emotional support and companionship, especially those who are alone or enduring long-term medical procedures. Pharmaceutical businesses hope to enhance patient involvement, satisfaction, and general well-being by introducing care robots into their settings.

7.1.2. BETTER MEDICATION MANAGEMENT:

By reminding patients to take their prescriptions on time, administering tablets in accordance with recommended schedules, and keeping track of medication adherence, care robots are anticipated to improve medication management. To make sure that the proper person receives medication at the right time, these robots can make use of cutting-edge technologies like speech and face recognition. Care robots improve treatment results and patient safety by lowering medication mistakes and encouraging adherence.

7.1.3. IMPROVED HEALTHCARE DELIVERY:

By enabling telemedicine consultations, remote monitoring, and patient education, care robots are anticipated to improve healthcare delivery procedures. With the help of these robots, patients can communicate with medical professionals from a distance, exchange health information gathered by the device's sensors, and get immediate assistance and direction. Pharmaceutical companies hope to improve access to healthcare services—especially for those who live in underdeveloped areas or have limited mobility—by incorporating care robots into telemedicine systems.

7.1.4. EMPOWERMENT OF HEALTHCARE PROFESSIONALS:

By helping with regular duties like drug administration, patient monitoring, and documentation, care robots are anticipated to empower healthcare personnel. These robots can improve workflow efficiency, lessen carer burnout, and allow healthcare professionals more time to concentrate on more difficult clinical duties. Care robots help provide high-quality patient care in pharmaceutical environments by enhancing the skills of healthcare workers.[25]

THINGS TO CONSIDER WHILE SELECTING A ROBOT:-

Selecting the appropriate robot for a certain clean room application is crucial, taking into account the environment's strictness and the robot's classification. Robots are certified based on the amount of particles they produce during motion, and this information is used to determine which industries and cleanrooms they can be used in. Robots frequently lose their dust from the motion of the robotic arms or the end effectors, and particles from gases from hoses and belts. When producing robots for the pharmaceutical, biotechnology, and medical industries, producers should make sure they are approved to meet cleanroom standards.[26]

STATUS OF ROBOTICS IN PHARMACEUTICAL INDUSTRY:-

Robots carry out a variety of activities in laboratories and pharmaceutical enterprises. These robots operate in hazardous or dangerous locations where they may be exposed to radioactive pollutants, biological dangers, or toxic chemotherapeutic agents.Numerous implants and medical devices are assembled and packaged using robotics in the packaging process. Additionally, robotics are utilised to fill prescriptions for hospitals and mail-order pharmacies.When an object is thin, swift, and flexible, robots can also be employed to pick it up and place it. Additionally, robots place customised orders and carry out activities like constructing blood sugar kits. Robots are useful for tasks involving drug research, test tube handling, and packing. PillPick is an automated pharmacy system designed to reduce medication errors that happen during packing and dispensing in hospitals while also improving patient safety.Additionally, robotics is employed in labs to facilitate productive operation. A couple of examples are SciGene, a robot that prepares DNA samples, and Varian's auto-sampler, a robot that picks up test tubes and loads them into an NMR (nucleus magnetic resonance) magnet. In order to achieve increased sustainability in their operations, several factories in the pharmaceutical industry had to reduce waste and pollution and use less energy. Since the gearboxes, motors, and drives that power robots have shown to be 95% energy efficient, robots may achieve these objectives. [27]

ROBOT MARKET ANALYSIS AND STUDY OF ROBOTIC PERFORMANCE TO PRICE RATIO:-

1. ROBOT MARKET ANALYSIS:

The need for automation and robotics in a variety of industries, including the pharmaceutical industry, has led to a notable increase in the worldwide robot market. Together with projections for potential expansion, market research reports offer insights into the robot market's size, trends, and development factors.[28] This report offers a comprehensive analysis of the robot market, including market size, segmentation by type and application, key players, and growth prospects. It provides valuable insights for stakeholders in the pharmaceutical industry looking to invest in robotics and automation.

2. STUDY OF ROBOTIC PERFORMANCE TO PRICE RATIO:

Robotics cost-effectiveness and best investment plan are determined by analysing the robots' performance to price ratio. Pharmaceutical firms can make well-informed judgements regarding the adoption and deployment of technology by consulting studies that compare the capabilities, pricing, and performance of various robotic systems. This study examines the cost-benefit ratio of industrial robots used in pharmaceutical manufacturing, taking into account variables including total cost of ownership, precision, speed, and dependability. It offers perceptions into the efficiency and cost-effectiveness of various robotic systems, assisting pharmaceutical organisations in optimising their automation plans.[29]

3. IMPACT OF ROBOTICS ON PHARMACEUTICAL OPERATIONS:

Evaluating how robotics will affect pharmaceutical operations entails looking at things like increased productivity, reduced costs, improved quality, and regulatory compliance. The advantages and difficulties of using robotics into pharmaceutical production, packaging, and distribution procedures are demonstrated via case studies and empirical research.Through case studies of businesses that have embraced robotic technologies, this study investigates how robotics has affected pharmaceutical operations. It evaluates robots implementation's performance, efficiency improvements, and return on investment, providing important information to pharmaceutical sector decision-makers.[30]

4. FUTURE TRENDS AND OPPORTUNITIES:

Developments in collaborative robotics, artificial intelligence, and machine learning are among the robotics trends and opportunities that the pharmaceutical sector will see in the future. Forecasts and insights into new applications, technology, and market factors influencing the direction of robotics in the pharmaceutical sector are offered by market analysts and industry specialists.This study examines the robotics market in the pharmaceutical business, highlighting significant trends, factors, and obstacles influencing the sector's future. It assists stakeholders in making strategic decisions by offering projections for investment opportunities, technological adoption, and market growth. For stakeholders looking to use robotics and automation to boost production, efficiency, and competitiveness, these sources provide in-depth market research on robots and a study of the robotic performance to price ratio in the pharmaceutical sector.[31]

5. APPLICATION OF ROBOTS IN PHARMACEUTICAL INDUSTRY:-

There are several segments within the pharmaceutical industry. Four sorts of production parameters are usually handled in any sector of these industries: cost, speed, quality, and adaptability. In the pharmaceutical industry, quality is mandated by law, but historically, speed and lower upfront costs have been the primary motivators. The adaptability of machines, systems, and facilities will more important in the future since it will be necessary to make fast modifications while maintaining outstanding manufacturing flexibility due to the unpredictability and complexity of goods, quantities, and markets. At the system level, continuous manufacturing is becoming more popular. Robotics and automation are being used for alternative drying technologies and oral medication items. [32]

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6. ROBOTICS IN STERILE MANUFACTURING:-

In the pharmaceutical business, robotics is essential to sterile manufacturing processes because it ensures contamination control, accuracy, and precision.

6.1. ASEPTIC FILLING AND PACKAGING:-

Aseptic filling and packaging processes use robotics to minimise human participation and lower the risk of contamination. Syringes, vials, and other containers are handled by robotic arms with sterile end-effectors, guaranteeing accurate dosing and sealing. Robotic systems that are automated can function in cleanrooms or isolators to preserve sterility during the production process. This study explores the use of robotics in aseptic filling and packaging processes, discussing the advantages, challenges, and regulatory considerations associated with robotic automation in sterile manufacturing.[33]

6.2. STERILE COMPOUNDING AND MIXING:-

Sterile compounding and mixing activities involve the use of robotics to create sterile formulations, intravenous (IV) solutions, and customised pharmaceuticals. With the least amount of contamination possible, automated robotic systems precisely measure and dispense materials, guaranteeing precision and reproducibility. In order to preserve safety and sterility, robotic compounding systems work in controlled conditions.The use of robotics in sterile compounding and mixing operations is examined in this article, emphasising the advantages of automation for enhancing precision, effectiveness, and regulatory compliance.[34]

6.3. STERILE FILTRATION AND PURIFICATION:

In sterile filtration and purification procedures, where exact control and monitoring are necessary to eliminate contaminants and pathogens from pharmaceutical products, robotics plays a part. Robotic systems provide consistent product quality and sterility by automating filtration, chromatography, and purification processes. In order to maximise process performance, real-time monitoring and filter parameter change are made possible by advanced robotic technology.In order to improve product quality and regulatory compliance, this research study explores the use of robots in sterile filtration and purification procedures. It also discusses the integration of robotic systems into pharmaceutical production activities.[35]

6.4. STERILE PACKAGING AND LABELING:-

Pharmaceutical products are handled, inspected, and labelled by robotics in sterile packing and labelling processes prior to delivery. Packaging line processes are automated by robotic equipment, guaranteeing precise product positioning, tamper-evident sealing, and label compliance. Robotic packaging systems incorporate vision systems and sensors to guarantee packing integrity and detect flaws.This paper examines the use of robotics in sterile packaging and labelling procedures and talks about how automation might increase productivity, traceability, and product safety in the production of pharmaceuticals.[36]

6.5. RESEARCH AND DEVELOPMENT (R&D):-

Already, the development of innovative drugs depends more and more on robots. In high throughput screening (H.T.S.), millions of compounds are assessed to determine which ones might become novel drugs. It is necessary to use robotics to test these millions of compounds. Like any other process, robotics involves using a robot to replace a human worker in a Repeated work can expedite this process significantly. [37]. For instance, robotic arms are frequently utilised in high-throughput screening procedures at Southern States University. A microplate is a compact, disposable container used in high throughput screening (HTS). Microplates are composed of plastic and have a grid of tiny, open wells that function as tiny test tubes to perform the necessary function. The number of wells varies depending on the type of microplate. For example, contemporary HTS microplates typically feature wells ranging from 384 to 9,600. With the use of robotics, sensitive detectors, liquid handling equipment, software for data processing, and system control, HTS enables the quick execution of millions of chemical pharmacological, or genetic experiments. This method allows for the quick identification of active substances, antibodies, or genes that alter a specific biomolecular pathway. These studies also serve as a basis for developing new drugs and comprehending the function and interactions of specific or chosen biological method. [38–39]

7. LABORATORY ROBOTICS:-

This new technology frees up human abilities to be concentrated on sample selection and submission, as well as scrutiny of the generated data, in place of tedious tasks that cause fatigue and mistakes. Of course, the expected benefits of this automation are better data and reduced expenses. Human fatigue and mistake in laboratory experiments are being eliminated by new robotics-based procedures. moving and cleaning. This includes analytical investigations that are fluorescent, luminous, and radioactive. Laboratory robotics is being used extensively in pharmaceutical development to help meet the demands of increasing productivity, decreasing costs, and speeding up the drug development process. The most common geometries for laboratory robots (multijointed, human-like configuration) are cylindrical (parallel action arm rotated around a central point), anthropomorphic, and cartesian (three mutually perpendicular axes).[40.41]

8. STERILIZATION AND CLEAN ROOMS:-

In clean rooms and sterilisation, robotics is essential to maintaining sterile conditions and effectively sterilising surfaces and equipment in pharmaceutical manufacturing facilities.

8.1. STERILISATION PROCEDURES:

Autoclaving, gamma irradiation, and vaporised hydrogen peroxide (VHP) sterilisation are just a few of the sterilisation procedures that robotics is used in during the pharmaceutical manufacturing process. Robotic solutions make it easier to handle and move items, containers, and equipment into and out of sterilisation chambers while maintaining sterility and according to regulations.In order to ensure the effectiveness and efficiency of sterilisation procedures, this research study discusses the importance of automation in robotics applications in pharmaceutical industrial sterilisation processes.[42]

8.2. CLEAN ROOM MAINTENANCE:

Robots are used in clean room maintenance to perform duties like disinfection, surface cleaning, and environmental monitoring. Robots outfitted with certain instruments and sensors traverse clean room settings, carrying out typical upkeep and cleaning tasks while reducing the possibility of contamination and upholding hygienic regulations.This study discusses the integration of robotic systems into clean room facilities to improve cleanliness and sterility as it investigates the function of robots in clean room maintenance in the pharmaceutical production industry.[43]

8.3. ENVIRONMENTAL MONITORING AND CONTROL:

In clean room settings, where maintaining precise humidity, temperature, and particle levels is essential for guaranteeing product quality and legal compliance, robotics play a role in environmental monitoring and control. Automated robotic systems with sensors and monitoring equipment constantly check their surroundings and change the control parameters to keep everything operating at peak efficiency.In order to ensure the stability and integrity of clean room environments, this research article discusses the importance of automation in robotics applications for environmental monitoring and control in pharmaceutical clean rooms.[44]

8.4. ROBOTIC DECONTAMINATION SYSTEMS:

In order to remove microbiological contaminants from surfaces and equipment in pharmaceutical clean rooms, robotics is used in the development and implementation of robotic decontamination systems. These robotic devices use cutting-edge technology like hydrogen peroxide vapour and ultraviolet (UV) radiation to quickly and effectively decontaminate without the need for human participation.The purpose of this study is to investigate how robotics can be used to improve cleanliness and sterility in pharmaceutical clean rooms through the development and application of robotic decontamination systems.[45]

8.5. PACKAGING PROCEDURES:-

Automation's consistency and speed are advantageous for packaging processes as well as other pharmaceutical procedures. Specifically, robotics provides accuracy and adaptability. Additionally, robotics can perform better than specialised machinery in some packaging tasks, such loading cartons. Pharmaceutical packaging machines are often made to fit particular product configurations, like vials.

9. ADVANTAGES OF ROBOTIC AUTOMATION OF PACKAGING:-

9.1. ENHANCED PRODUCTIVITY AND EFFICIENCY:

Robotic automation increases productivity and throughput by optimising packaging

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operations. Robots can perform packing duties quickly and precisely, cutting cycle times and increasing total productivity.[46]

9.2. ENHANCED PRECISION AND QUALITY MANAGEMENT:

Robots carry out packing duties with exceptional precision and uniformity, reducing mistakes and flaws. Robots can examine packaging materials and confirm product integrity thanks to automated vision systems and sensors, guaranteeing premium packaging standards.[47]

9.3. FLEXIBILITY AND ADAPTABILITY:

Robotic packaging systems are highly adaptable, allowing for simple programming or reconfiguration to suit a wide range of product variations, sizes, and packaging types. Because of this adaptability, producers of pharmaceuticals are able to react rapidly to shifting consumer needs and production specifications.[48]

9.4 . ENHANCED WORKER SAFETY:

Robots lower the risk of workplace injuries by automating repetitive and possibly dangerous packaging operations. Workers may be moved to more important jobs that call for judgement and human knowledge.[49]

10. OTHER USE OF ROBOTS:

10.1. 3D PRINTING

In the manufacturing sector, 3D printing has been actively utilised for creating complex contact components and fast prototyping. The pharmaceutical sector is slowly integrating the technologies. In both industry and academia, 3D-printed pills as well as pharmaceutical medicine products and gadgets have been the focus of much research. [50]

10.2. QUICK PROTOTYPING MAKING USE OF 3D PRINTING:

Additionally, lab-scale operations, innovative packaging, device ideation, and the ability to realise a large number of concepts in previously unheard-of turnaround times can all benefit from 3D printing. In a lab, repairing a damaged component, creating components that performance and outcomes can be significantly impacted by conducting tests and cutting out unnecessary tasks. For instance, because of the focus on biologics and device development—both of which can be significantly impacted by 3D printing—the use of parenteral medicinal products is steadily rising. Quick idea-to-physical part translation enables the implementation of innovative innovations and effective evaluation of user experience. .. Patients may also benefit from packaging solutions that save expenses and make complicated equipment use easier. Because of its capacity to influence several aspects of medication product development, 3D printing is therefore set to become a future mainstay. [51]

10.3. ENDOSCOPIC VIDEO CAPSULE MAGNETIC ROBOTIC MANIPULATION:

A decade ago, in clinical praxis, the use of ingestible video capsules for gastrointestinal explorations of the digestive tube was introduced. Since then, the technology has been steadily improving and is still being used today. Since Yoqneam, Israel's Given Imaging Ltd. produces the most atypical commercial product is the M2A capsule. A stunning outcome of significant advancements in microelectronics, this pill-shaped gadget mixes image capturing, wireless data transfer, and power supply capabilities in a compact container (26 11 mm, 3.23 g). The patient swallows it, and it passes through the digestive canal and eventually leaves the body on its own. Throughout its normally eight-hour operation, the video capsule automatically captures photographs and illuminates the wall of the gastrointestinal tube. Wireless transmission of the gathered data is made to an external wearable recorder. After the surgery is complete, the doctor can analyse the recorded data offline by downloading the video frame sequence from the recorder onto a workstation and reconstructing it. Video endoscopy in a capsule is expanding in the field of gastroenterology because to its ability to provide comfortable, non-invasive optical examinations of the digestive tube. [52]

10.4. ROBOTS FOR OCULAR DRUG DELIVERY :

When feasibility tests on magnetic manipulation and control of microsystems in bodily fluids were carried out approximately 20 years ago, the idea of using microrobots for drug administration in the eye was initially imagined. The purpose of these implants was to be used a 23-gauge needle and topical anaesthesia to inject into the vitreous cavity through the durable pars plana region. Electromagnetic fields and gradients were then used to direct the needle towards the retina. The cornea, lens, and vitreous are transparent, therefore an ophthalmoscope with a camera pointed

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towards the eye could track their positions optically. Microrobots sees the platform being utilised for retinal vein cannulation as well as medicine administration that dissolves clots. Multiple techniques such as thin layer deposition, sputtering, stereolithography, soft lithography, and 3D printing can be employed to microfabricate intricately shaped 3D magnetic devices. [53]

10.5. NANO ROBOTS :

Nanorobots are little robots, also known as tiny machines, that can readily navigate inside the human body. A patient's body would be searched for contaminated cells by a nano robot, which would then repair them without endangering the wholesome cells. To prevent any chance of harming the intracellular skeleton, the nano manipulators of the nano robots will enter the damaged or targeted cell while the nano robots stay outside. When these nanorobots enter the human bloodstream, they can significantly extend life through cell surgery, for example. Better acting, sensing, and communicating all depend on coordination, which presents a significant research issue. [54,55]

1.AUTOMATION:

In the pharmaceutical sector, automation is the use of machines, systems, and technology to carry out numerous jobs and procedures with the least amount of human intervention. It entails integrating software, robotics, and automated technologies to expedite quality control, packing, production, and other processes in pharmaceutical plants. The goal of automation is to decrease labour costs, errors, and cycle times while increasing efficiency, accuracy, and consistency.[56]

2.TARGETED DETECTION OR ADVANCE DETECTION:

A once-in-a-lifetime diagnostic process called prediscovery is used to choose a legitimate target molecule.Based on research on biological evolution and illnesses, it is said that Medical researchers formulate theories regarding the mode of action based on their investigations into the following processes: the alteration of genes, the impact of these changes on coded proteins, the integration of these proteins in living cells, the modification of specific tissues in the affected cells, and the combined effect of all these processes on the patient under targeted biological selection.[57]

3. DRUG DISCOVERY:

Drug discovery automation in the pharmaceutical industry involves the use of automated technologies and robotics to expedite the process of identifying and developing new drug candidates

3.1. HIGH-THROUGHPUT SCREENING (HTS):

To screen vast compound libraries against disease targets in a high-throughput manner, automated devices are used. These systems include robotic platforms and liquid handling instruments. These methods speed up the process of identifying possible drug candidates by enabling the fast testing of thousands to millions of chemicals.

3.2. COMPOUND SYNTHESIS AND CHARACTERIZATION:

Automated synthesis platforms facilitate the efficient generation of compound libraries for screening purposes. Additionally, robotic systems are employed for the characterization and analysis of synthesized compounds, such as determining their chemical properties and biological activities.

3.3. DATA ANALYSIS AND DECISION SUPPORT:

Drug discovery relies on automation technology for data analysis and decision support. Researchers can make more informed decisions by using machine learning algorithms and computational models to prioritise candidates for additional study, forecast compound actions, and analyse screening data.

3.4. HIT-TO-LEAD OPTIMISATION:

By making it easier to synthesise, screen, and characterise analogues and derivatives of hit compounds, automated processes aid in the hit-to-lead optimisation process. Multiple analogues may be tested in parallel thanks to robotic equipment, which speeds up the process of finding lead compounds with better potency, selectivity, and pharmacokinetic characteristics.[58]

4. PRE-CLINICAL TRIALS AND CLINICAL TRIALS:

Software that is random is used to alter learning designs and eliminate bias. Software for remote data capture, electronic data photocopying, and electronic case report (eCRF) forms are used in pre-clinical research to store data. Managing clinical data and doing statistical analysis for Data

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software in successful usage includes eClinical, Oracle Clinical, Clindex, Ascend (with Biopharm), and Clinical Conductor Clinical Trial Management System (CTMS) (with Bio Optronics). They support computerised planning, data entry, collecting, and interchange, as well as performance, management, analysis, and case reporting.[59,60] Through an Internet connection, electronic data capture (EDC) offers simple installation instructions straight from the software. [61,62] Developer statistics rely on eBig Data Management (BDM) technology to help with data resolution, news reporting, and support for specialised tools and resources for data synchronisation and familiarity. Medical records and tracking data can be properly maintained and extracted with big data management (BDM).

5. SETTING UP A FRESH MEDICATION APPLICATION:

The following are the electronic controlled submissions: endorsed by the Centres for Drug Testing and Research (CDER) and the Centre for the Evaluation and Research of Biologics (CBER) of the Food and Drug Administration (FDA). [63] Following An electronic document that is standard is used to create them (eCTD). Following submission of the data to the Food and Drug Administration (FDA) and receipt of the information, I Electronically, the report is delivered to the shipping gate (ESG).[64]

6. RESEARCH AND DEVELOPMENT:

The study also used silico testing in its development. Silico tests are carried out in research and visual development (e-RandD) utilising a hardware once Computer-assisted design project (FCAD). [65,66] Robotics, namely the control of electro-mechanical systems, is another science utilised in research and development (R&D).[67] Software modules were used to build the formulation-computer aided design (F-CAD) based on the mobile concept. Automata for determining a chemical substance's melting profiles as a structural activity and physical-chemical characteristics of the formation's constituents (such as melting, swelling, the impact of assistants and particle size distribution, etc.). [68,69] technology for three-dimensional (3D) printing. Three-dimensional technology is a different type of prototype technology. able to manufacture solid dose forms with different capacities, intricate interior geometries, diffusivities, and assistants. In order to generate a three-dimensional (3D) item by arranging material on the substrate, it also makes use of computer-aided drawing technology (CAD). [70]

7. PRODUCTION AND PRODUCTION MANUFACTURING:

Automation in pharmaceutical production and manufacturing encompasses a wide range of technologies and systems aimed at improving efficiency, consistency, and quality in the production of pharmaceutical products.

7.1. AUTOMATED PRODUCTION PROCEDURES:

Many production operations, including as compounding, mixing, granulating, tablet pressing, capsule filling, and packaging, use robotics and automated systems.Automated machinery and equipment reduce manual labour and mistake risk by performing repetitive activities with high precision and consistency.

7.2. SYSTEMS FOR CONTINUOUS MANUFACTURING:

Unlike traditional batch processing, continuous manufacturing systems use automated procedures to generate pharmaceutical items in a continuous flow.Benefits from these systems include shorter manufacturing times, better-quality products, and better process control.

7.3. ASSURANCE AND CONTROL OF QUALITY:

Pharmaceutical product safety, effectiveness, and compliance are guaranteed by the use of automation technology in quality control and assurance procedures.Automated inspection systems identify flaws, irregularities, and pollutants in final goods, packaging, and industrial machinery. These systems include vision inspection and machine learning algorithms.

7.4. PROCESS OBSERVATION AND ENHANCEMENT:

Automated monitoring systems gather data in real time on variables like temperature, pressure, and flow rates while continuously monitoring production operations.Proactive intervention and process optimisation are made possible by these systems in order to preserve product quality, reduce waste, and increase efficiency.[71]

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8. ROBOTS TO PRODUCE PERSONAL MEDICINE:

Invetech and Argos Therapeutics, biopharmaceutical partners, have developed an automated production system for personalised immunotherapy based on Argos' Arcelis Technology. The system uses two robotic arms with five axles to generate messenger ribonucleic acid (mRNA). generated on equipment used to process cells is utilised as an antigen uploading to dendritic cells taken from a patient's tumour. Automation is used by mobile devices to treat white blood cells while they are being produced, regulating their proliferation and maturation into dendritic cells. These cells generate the necessary antigens, which when given to the patient will result in The patient's immune system will target metastatic cells by producing killer T-cells. [72]

9. PAPERLESS PRODUCTION SYSTEM:

The transition towards paperless production systems in the pharmaceutical industry involves the implementation of digital technologies and automation to streamline manufacturing processes, improve data integrity, and enhance regulatory compliance.

9.1. BATCH RECORDS ELECTRONICALLY (EBR):

Electronic batch records are digital systems that take the role of traditional paper-based batch records for recording production activities, process details, and product specifications.'

EBR systems ensure data integrity and regulatory compliance by offering electronic signatures, audit trails, and real-time data collection.

9.2. INSTRUCTIONS FOR ELECTRONIC WORK (EWI):

Standard operating procedures (SOPs), work protocols for operators and technicians, and manufacturing methods are all digitalized through electronic work instructions.

EWI systems improve operator accuracy, efficiency, and training by providing interactive, step-by-step instructions, multimedia information, and visual assistance.

9.3. MANAGEMENT OF DIGITAL DOCUMENTATION:

Manufacturing paperwork, such as SOPs, procedures, specifications, and batch records, is centralised and organised using digital documentation management systems.

Version control, revision tracking, and document retrieval are made easier by these solutions, which also cut down on paperwork, mistakes, and administrative burden.

9.4. SYSTEMS OF INTEGRATED AUTOMATION:

To provide a smooth production environment, integrated automation systems link data management software, control systems, and manufacturing equipment.These systems optimise production performance and compliance by enabling automated data interchange, process monitoring, and closed-loop control. [73]

10. DIGITALIZATION IN QUALITY CONTROL AND QUALITY ASSURANCE:-

In light of quality assurance and control, quality control is fundamental. Market inspections and testing validate producers of pharmaceuticals or medicine that meets product grade; it's a very efficient operation.[74] The International Conference on Harmonisation (ICH) Q10 model, which is based on the Good Manufacturing Practices (GMP) and In accordance with the International Organisation for Standardisation (ISO) Quality principles, is frequently used to refer to medicinal quality control. The International Conference on Harmonisation (ICH) "Q9 Quality Risk Management" and the International Conference on Consensus (ICH) "Q8 Drug Development" Three are included in the International Conference on Harmonisation (ICH) Q10

Principal goals:

1. Realising product fulfillment
2. Create and keep a controlled atmosphere.
3. Encourage more growth. [75]

11. HIGH QUALITY RISK MANAGEMENT:-

It offers a practical approach to identifying, evaluating, and controlling possible quality hazards using science. It supports ongoing process performance and product quality enhancements over the course of the product life cycle. [76] Design quality It is a quality system designed to oversee the life cycle of a product. The multifunctional function's goal is to maximise output and process. comprehending and lowering patient risk as a result. Document requirements establish the process known as Quality with Design, or QbD. [77]

12. PROCESS ANALYSIS TECHNOLOGY (PAT):-

The Food and Drug Administration (FDA) in the United States launched the Process Analytical Technology (PAT) regulatory programme to support the adoption of novel techniques in pharmaceutical manufacturing. Throughout the production process, PAT uses real-time monitoring, measurement, and control of quality attributes (CQAs) and critical process parameters (CPPs).

13. MONITORING AND CONTROL IN REAL-TIME:-

With PAT, important process variables including temperature, pressure, pH, and particle size distribution may be continuously and instantly monitored and controlled.Process variables and product attributes are measured by automated sensors, analyzers, and spectroscopic techniques, which give operators and control systems immediate feedback.

14. APPROACHING QUALITY BY DESIGN (QBD):

PAT is in line with the Quality by Design (QbD) paradigm, which places a strong emphasis on developing strong control mechanisms and comprehending the variability of processes and products.

Automation technologies help to assure product quality and consistency by enabling the methodical assessment and optimisation of manufacturing processes, which is in line with QbD principles.

15. MULTIVARIATE DATA ANALYSIS (MVDA):

Complex datasets produced by PAT systems are analysed using MVDA techniques to find patterns, correlations, and linkages between process variables and product qualities.Based on statistical models and predictive analytics, automated data analysis algorithms and software tools help to extract useful insights and optimise process performance.

16. SYSTEMS OF CLOSED-LOOP CONTROL:

Closed-loop control systems, in which process modifications are made in reaction to variations in crucial parameters or product quality, are made possible by PAT.Automated feedback loops and control algorithms govern process conditions in real-time, maintaining optimal operating conditions and ensuring product uniformity and compliance.[78]

17. PACKING AND LABELING:-

A variety of equipment animation techniques are used in the packing system, including with labeling , shrinking, closing, case and tray construction, assembling, cooling, and drying, feeding, pouring, picking, and installing (robotic systems), cleaning, disinfecting, and diagnostic procedures. as well as diagnostic tools. There are several techniques used in packing. A theoretical technique called fixed atmosphere packing (MAP) reduces oxygen and burns carbon dioxide. The sophisticated packaging that she uses for her clever packing is meant to be used by perceptive people. Pathogen identification and contamination tracking are accomplished by packaging that is based on nanotechnology [79]. Technology that fights fraud is being compelled to combat fraudulent medicine items [80,81].

18. SALES AND MARKETING:-

Bulk, an inefficient paper-based procedure, and the risk of human error make it a monotonous operation. To alter the game, the quickest software-driven technique for managing workflow and recording has taken the place of the outdated paper document method with electronic bulk recording. preserving every detail from the recipe's creation for the degree collection.

[82] This is used to get batch agreements, shorten the time it takes to examine the collection documents, and remove the necessity for physical record transfers between channels.

[82] On the internet both competent and gentle Pharmaceutical companies have been encouraged to invest in and explore digital marketing strategies within industry guidelines by health care experts (HCP), key opinion leaders (KOLs), senior officials, and communities developed to adapt to increased mobile usage, communication platforms, and online patient information. [83] Digital media offers continuous customer and advertising connection. New internet media, known as electronic data (e-Detailing) that prescribes medication to doctors, will be sent to pharmaceutical corporations. Small attempts made by pharmacy companies with these burgeoning apps. Within pharmaceutical firms, Johnson and Johnson was among the initial ones to start the

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YouTube channel. The Specials Lab, a North East-based pharmaceutical company, and Quantum Pharmaceuticals offer online ordering for specialty pharmaceuticals while fostering e-commerce and digital marketing [83].

19. THE TYPES OF DIGITAL MARKETING USED ARE:-

1. Search engine optimization (SEO)
2. Social Media Marketing.
3. Pay By Clicking Ads.
4. Email Newsletters[83]

20. PHARMACY FOR SALE:-

Plans are created to make possible distribution easier. consists of a duplicate electronic design (eRD) and an electronic prescription (eRx). When it comes to electronic prescriptions, direct pharmacies Obtain a doctor's prescription—a paperless prescription. digital summaries are beneficial for safety since they shield patients from harm, give access to their medical records, and help They prescribe medications that a patient may use, medications that won't combine with other prescription medications. It temporarily restores the chemist's composure. Handwritten instructions may lead to the incorrect drug or dose being prescribed.The use of physician electronics (eRx) in diagnosis The patient's insurance pays for covera medication that patients can purchase.[64] Using a single digital signature, electronic repeat design (eRD) enables the authorization and issuance of several repetitive orders for a maximum of 12 months. The National Health Service's Electronic Repeat Design (eRD) maintains all of its news securely. (NHS) Spine and, if directed by a physician, refer them to a designated patient provider. The doctor's prescription may be changed or cancelled at any moment by the prescriber.[84]

II. CONCLUSION:-

In summary, the pharmaceutical industry's adoption of automation and robots signifies a revolutionary change in the way medications are found, created, produced, and delivered. Automation technologies provide major advantages in terms of efficiency, accuracy, and quality across the drug development lifecycle, from research and development to manufacture and distribution.First, high-throughput screening and automated synthesis platforms facilitate the quick identification and refinement of possible drug candidates, which speeds up innovation in the drug development process. Automation in manufacturing increases regulatory compliance, decreases errors, and streamlines production processes—all of which contribute to better pharmaceutical product availability and consistency. Automation also makes it easier to put advanced quality control procedures into practice, like data analysis and real-time monitoring, which guarantee patient safety and high-quality products.Furthermore, robotics are essential to many pharmaceutical processes, including as distribution, warehousing, and packaging. Medication packaging efficiency and accuracy are enhanced by automated packaging systems, and warehouse management and logistics are optimised by robotic arms and automated guided vehicles. These developments lower expenses, raise production, and lower the possibility of mistakes and contamination. All things considered, automation and robots provide a great deal of promise for the pharmaceutical sector, providing chances for improvement in efficiency, innovation, and patient outcomes. Further automation and robotics integration is anticipated to propel ongoing progress in medication development, production, and distribution as technology develops, ultimately helping pharmaceutical businesses and patients globally. However, in order to overcome obstacles and optimise the advantages of these technologies, ongoing investment in R&D and regulatory harmonisation will be necessary to fully realise the potential of automation and robotics in the pharmaceutical business.

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