

# A Review on: Artificial Intelligence in Quality Control

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**Abstract**—In recent decades the demand for high quality and accuracy in pharmaceutical industry has increased significantly due to customer expectation and complexity of modern projects. Artificial intelligence (AI) upgrades the quality control by automated inspection, error detection with greater precision and speed than humans. Artificial intelligence(AI) is transforming modern quality control(QC) system by faster and highly automated decision-making processes across manufacturing and services industries. Traditional quality control(QC) systems, depend on manual inspections and human oversight, often all short in delivering consistency, speed, accuracy and higher operational costs. This review explores how artificial intelligence (AI) technologies are reshaping the landscape of quality control(QC) in pharmaceutical industries. Artificial intelligence (AI) driven approaches such as machine learning, deep learning, computer vision and predictive analytics significantly increases the precision and efficiency of quality evaluation. Overall artificial intelligence(AI)-integrated quality control system offers remarkable benefits including increase accuracy, reduced inspection time, cost saving, and improved decision-making, ultimately contributing to higher productivity and competitive benefits.

**Keywords**—Artificial intelligence(AI), Quality control(QC), Computer application, Machine learning, Manufacturing, Test methods.

## I. INTRODUCTION

Artificial intelligence (AI) is the branch of computer science that enables machines to perform tasks that normally requires human intelligence. It is the study of ideas which enables computers to do the things that make people seem intelligent. The central principles of AI include such as reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects. It is the science and engineering of making intelligent machines, especially intelligent computer programs.

According to father of artificial intelligence John McCarthy, who coined the term “Artificial Intelligence” in 1956 said that “It is the combination

of science and engineering to make intelligent devices for human welfare.” Artificial intelligence is an intellect that is much smarter than the best human brain in practically every field, including computer science and linguistic logic. It is a modern method of machines which will do muscle work and illustrate complex question in a “intellectual” manner. It is concerned with the basic and most important aspects in our life i.e., philosophy, computer science, mathematics, linguistics, biology, neuron science, sociology etc. AI plays a very important role to exhibit intelligent behavior, to learn, demonstrate and give advice to the user.

Artificial General Intelligence or AGI is a system that defines that the machine can do to artificial intelligence is that it can be the combination of learning, perception, problem solving and adapting new solution to the system. This basically defined for development of software which is used for solving complex problem using application process.

Historical development of artificial intelligence in quality control:

The application of Artificial Intelligence (AI) in quality control has evolved significantly over the past few decades. Initially, quality control processes depended heavily on manual inspection and statistical techniques. These traditional approaches were often slow and susceptible to human error. During the 1980s, expert systems represented the earliest form of AI used in industrial quality control. These systems relied on predefined rules and logic to detect defects and analyze production parameters. Although limited in adaptability, they laid the foundation for automated quality assessment. By the 1990s, machine learning algorithms began to emerge, enabling systems to learn from historical data. Neural networks were introduced to identify complex patterns and predict quality outcomes. This marked the transition from rule-based systems to learning-based systems. In the 21<sup>st</sup> century, advancements in computing power, cloud computing, and big data analytics significantly enhanced the capabilities of AI

systems. Deep learning and computer vision technologies enable automated defect detection, visual inspection, and predictive quality monitoring. Today, AI plays a critical role in pharmaceutical quality control through automated inspection, process optimization, and risk management. The integration of AI with Internet of Things (IoT) devices and real-time sensors has further strengthened quality monitoring systems.

Types of artificial intelligence used in quality control:

1) **Narrow Artificial Intelligence (NAI) Weak AI:** Narrow artificial intelligence is the most common type of AI used today. It is designed to perform only one specific task or a limited number of tasks. Unlike humans, it cannot perform tasks beyond what it has been programmed to do. However, within its specific function, Narrow AI can perform tasks very efficiently and accurately. For example, in pharmaceutical industries, Narrow AI systems are used to inspect tablets and capsules for defects. These systems can quickly identify cracks, color differences, or irregular shapes that may not be easily noticed by human inspectors. Similarly, AI-based systems can monitor environmental conditions such as temperature and humidity during drug manufacturing to ensure product stability. One of the major advantages of Narrow AI is its speed and precision. It reduces human error and allows industries to maintain consistent product quality. However, its main limitation is that it cannot think beyond its programmed purpose. If a new type of problem arises outside its training, it cannot handle it without additional programming or retraining.

2) **General Artificial Intelligence (AGI) Strong AI:** General Artificial Intelligence refers to machines that can perform tasks in the same way humans do. Such systems would be capable of understanding problems, reasoning, learning from experience, and making decisions across different areas. Unlike Narrow AI, which focuses on specific tasks, General AI would be able to perform many tasks without needing separate programming for each one. At present, General AI has not been fully developed. It remains an area of active research. Scientists aim to create systems that can think, learn, and adapt similarly to humans. If achieved, General AI could transform pharmaceutical quality control by allowing machines to manage entire production systems, identify problems

independently, and make intelligent decisions without constant human supervision.

Technologies supporting artificial intelligence in quality control:

1) **Big data analytics:** Big data analytics plays a major role in supporting AI systems used in quality control. Pharmaceutical manufacturing produces a large amount of data at every stage, including raw material testing, production processes, laboratory analysis, and final product inspection. Managing such large volumes of data manually would be very difficult and time-consuming. Big data technologies make it possible to store, organize, and analyze this information efficiently. By analyzing large datasets, AI systems can identify patterns and trends that may not be easily visible to humans. For example, if a particular defect appears repeatedly under certain conditions, big data analysis can help to identify the cause. This allows manufacturers to correct the problem before it affects product quality. Another important benefit of big data analytics is its ability to support real-time decision-making. Data collected during production can be analyzed immediately, allowing operators to detect problems early and take corrective action. This reduces waste, improves efficiency, and ensures consistent product quality.

2) **Internet of Things (IoT):** The Internet of Things (IoT) refers to devices connected through sensors that collect and share information automatically. In pharmaceutical manufacturing, IoT sensors are installed in equipment to monitor important factors such as temperature, humidity, pressure, and flow rate. These sensors continuously send data to AI systems, allowing them to monitor the manufacturing environment in real time. For example, if the temperature inside a drying unit increases beyond the safe limit, the AI system can detect the change and alert operators immediately. This helps prevent product damage and ensures quality standards are maintained. IoT also allows remote monitoring of manufacturing processes. Quality control teams can check production data from different locations without being physically present. This makes quality monitoring more efficient and reliable.

3) **Cloud computing:** Cloud computing provides the storage and computing capacity needed for handling large amounts of data generated in quality control processes. Instead of storing data on individual

computers, cloud platforms allow data to be stored on remote servers that can be accessed through the internet. In pharmaceutical quality control, cloud computing allows companies to safely store laboratory reports, inspection results, and production data. AI system can use this stored data to analyze trends and predict future outcomes. Cloud platforms also allow faster data processing, which improves the speed and accuracy of decision-making. Another advantage of cloud computing is its ability to support collaboration. Different departments, such as production, quality control, and research, can access shared data from any location. This improves communication and ensures that all teams work with accurate information.

4) Robotics and Automation: Robotics and automation technologies are widely used in modern quality control systems. Robots are designed to perform repetitive tasks with high precision and consistency. When combined with AI, robots can perform inspections, handle materials, and carry out packaging operations efficiently. In pharmaceutical industries, robotics systems are often used to collect product samples, inspect tablets, and pack finished products. For example, robotic arms can move products from one stage of production to another without causing damage. This reduces the risk of contamination and ensures consistent product handling. Automation also reduces the need for manual labor in repetitive tasks, lowering the chances of human error. It improves production speed and helps maintain uniform quality standards.

5) Machine Learning Algorithms: Machine learning (ML) algorithms form the foundation of many AI systems used in quality control. These algorithms allow machines to learn from previous data and improve their performance over time. In pharmaceutical quality control, machine learning systems analyze production data and identify patterns that may indicate defects. For example, if certain process conditions lead to poor product quality, the system can recognize this pattern and predict similar problems in the future. Machine learning also helps in classifying products as acceptable or defective and predicting shelf life or stability. By learning from past data, these systems continuously improve their accuracy and reliability.

6) Deep Learning Technology: Deep learning is an advanced form of machine learning that uses complex neural networks to analyze large and

complicated datasets. It is especially useful for processing images and recognizing patterns. In quality control, deep learning systems are commonly used for visual inspection. For instance, thousands of images of tablets can be analyzed quickly to detect defects such as cracks, discoloration, or uneven coating. These systems can identify even very small defects that may not be visible to the human eye. Although deep learning systems are highly accurate, they require large amounts of data and powerful computing systems to function effectively.

7) Computer Vision Technology: Computer vision technology allows machines to see and understand visual information from images or videos. It is widely used in automated inspection systems in pharmaceutical manufacturing. During production, cameras capture images of products moving along the production line. These images are analyzed by AI systems to check for defects such as broken tablets, incorrect shapes, or missing labels. Computer vision systems can inspect products much faster than humans, making them suitable for large-scale manufacturing. By automating visual inspection, computer vision improves accuracy and reduces reliance on manual inspection.

8) Natural Language Processing (NLP): Natural Language Processing (NLP) enables computers to understand written and spoken language. In quality control, large amounts of textual data are generated in the form of reports, documentation, and regulatory guidelines. NLP systems can analyze these documents to identify missing information, errors, or inconsistencies. They can also help generate reports automatically based on collected data. This reduces the amount of manual paperwork and improves documentation accuracy. In pharmaceutical industries, proper documentation is essential for regulatory compliance. NLP helps ensure that records are complete, accurate, and easy to manage.

9) Edge Computing: Edge Computing is a technology that processes data near the source of data generation instead of sending it to a distant server. This reduces the time required for data processing and allows for faster responses. In quality control systems, edge computing helps analyze data from sensors immediately. For example, if a machine begins to operate outside safe limits, the system can detect the issue instantly and alert operators. This quick response prevents damage and ensures continuous production. Edge computing is especially

useful in situations where real-time monitoring is necessary.

10) Digital Twin Technology: Digital Twin Technology involves creating a virtual model of a physical system. This model behaves like real manufacturing process and allow engineers to test different conditions without affecting actual production. In pharmaceutical quality control, digital twins can simulate production processes and identify possible problem before they occur. For example, manufacturers can test how changes in temperature or mixing time affect product quality without interrupting real production. Digital twin technology improves understanding of manufacturing processes and helps prevent costly errors.

Advantages and Disadvantages:

1) Advantages:

- ◆ Improved accuracy and precision
- ◆ Faster inspection and processing
- ◆ Reduction in human error
- ◆ Predictive maintenance
- ◆ Real-time monitoring and control
- ◆ Cost reduction
- ◆ Enhanced data analysis and decision-making
- ◆ Consistency in quality standards
- ◆ Improved traceability and documentation
- ◆ Ability to handle complex processes
- ◆ Increased productivity
- ◆ Early detection of defects

2) Disadvantages:

- ◆ High initial investment cost
- ◆ Requirement of skilled personnel
- ◆ Dependence on high-quality data
- ◆ Risk of system failures
- ◆ Limited human judgment and creativity
- ◆ Data privacy and security concerns
- ◆ High maintenance and upgrade costs
- ◆ Integration challenges with existing systems
- ◆ Lack of transparency

## II. CONCLUSION

Artificial intelligence brought a noticeable change in the way quality control is carried out in modern industries. Instead of relying only on manual inspection methods, many organisations are now using intelligent systems that can monitor processes, identify defects, and analyze data much faster and more accurately. Techniques such as machine learning, computer vision, deep learning,

and predictive analytics have made it possible to move toward smarter and more reliable quality control practices. These technologies help industries detect problems at an early stage, maintain consistent product quality, and improve overall efficiency. The use of AI in quality control offers several practical benefits. It increases accuracy, speeds up inspection processes, and reduces the chances of human error that often occur due to fatigue or repetitive work. AI systems also help in predicting machine failure and maintaining equipment before problem occur, which supports uninterrupted production. In addition, AI helps industries reduce waste, lower production costs and make better decisions by analyzing large amount of data. In fields where maintaining strict quality standards is very important, such as pharmaceutical manufacturing, AI supports compliance with required guidelines and helps maintain product safety and consistency. Overall, Artificial Intelligence has shown strong potential to improve quality control systems and make them more efficient and dependable.

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