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Integration of Robotic Automation in Manufacturing: Benefits and Challenges for Quality Assurance

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ABSTRACT: Robots have helped revolutionize manufacturing processes by lending an assisting hand to humans. Robots have proven to be more effective and efficient than humans, even though humans still possess the mental prowess to help them function. Robots assist in activities like assembling, carrying heavy objects, performing strenuous tasks, welding mechanical parts, and quality inspection. Robots have several advantages over humans like being more accurate, cost effective, faster, and reliable. Nevertheless, robots still have their downsides like being too costly to implement and technically complex, especially for small businesses. This research paper comprehensively assesses the integration of robotic automation in manufacturing, focusing specifically on its benefits and challenges for quality assurance. Quality assurance is an essential component of the manufacturing process, as without it the process is never complete, manufacturing industries adhere to specific standards for their products to avoid causing harm to the end consumer in the long run, hence the relevance of robotic automation in this process. Robots are very relevant in the aspect of quality assurance, as they possess special devices which help in inspecting products during and after production. Through a thorough review of articles on this subject matter from reliable databases, this article discusses in details and suggests better ways of integrating robots in industries for more effective quality assurance.

KEYWORDS: Automation, Cobots, Industry 4.0, Manufacturing, Quality Control, Technology, Robots.

1. INTRODUCTION

In recent years, robots have been used in almost every area, especially in manufacturing, where they offer many benefits. Robots are important in transforming the manufacturing industry (ElMaraghy et al., 2021). This is because it can lower mistakes, make work faster and more accurate, and help employees focus on more difficult tasks by taking care of repetitive and time-consuming jobs (Cohen et al., 2019). Unlike other automation tools, robotic automation can perform tasks without causing significant distortions or high costs (Asatiani & Penttinen, 2016) because it works quietly and smoothly with existing IT systems. It can be set up to learn from past experiences (Willcocks et al., 2017), which helps it get better over time. Robotic automation is a robust technology that helps businesses work better (Radke, Dang, & Tan, 2020) and save money by automating boring, repetitive tasks. As businesses use new technologies to work better, minimize costs, and make better products, adding robots has become an important part of this transformation brought about by industry 4.0 (Soori et al., 2024). The move from traditional industrial robots to advanced robotic systems that use artificial intelligence (AI) and machine learning has changed how manufacturing works (Adebayo et al., 2024). These improvements have not only made the industry more accurate and productive but have also allowed robots to make their own decisions. Robots used in manufacturing have come a long way. We began with traditional robotic arms doing the same tasks over and over, and now we have collaborative robots (cobots) (Soori et al., 2024) that work together with people. The range of ways we use robots in factories has grown a lot.

Companies that successfully use robotic process automation and have smooth business processes have noticed positive effects on their goals, worker productivity, and customer service (Lacity & Willcocks, 2016). These organizations can carry out their tasks quickly and for less money (Lacity & Willcocks, 2016; Schmitz, et al., 2019), because of this, they have gotten a lot of attention from the media. This creates a problem because workers might think that robots will completely take over their jobs soon. However, the preeminent thing about this situation is that robots will never fully replace humans. The goal is to find the best way for humans and robots to work together.

In large-scale production, a robot can work quickly and consistently (Papavasileiou et al., 2024), but it struggles to adapt to problems and unexpected situations. Humans can think of ways to solve problems, but they aren't fast, can't do the same thing over and over, and can't lift heavy things. This makes them less efficient, which can lower the quality of the final product or service. To reach

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these manufacturing goals while making customized products, it's important to find a balance between using machines and staying flexible.

Robots are now used everywhere, from car factories to complex electronics production. They help make things work better and produce more items (Javaid et al., 2021). The rise of Industry 4.0 has led to a huge increase in digitalized (Chryssolouris et al. 2009) robotic application in manufacturing for tasks like quality assurance. Many efforts have been put into using automatic quality control systems, which include both robots and people, especially in workplaces where they work together. These solutions were either about checking the product itself or watching and managing the processes and resources involved.

This study evaluates how robots can be integrated into manufacturing for better quality assurance. This research aims to find out:

i. The benefits of integrating robots in manufacturing;
ii. How robotic automation helps the quality assurance process in manufacturing; and
iii. The challenges of integrating robots in manufacturing.

This study employs a qualitative methodology to answer the research questions. A thorough review was conducted using reliable research database to get the data for this study.

The remaining sections of this paper are organized as follows; section two deals with the background and literature of the study, the third section deals with the methodology employed for this study, section 4 deals with the integration of robotic automation in manufacturing, evaluating the benefits and challenges for quality assurance, and section five concludes this study.

2. BACKGROUND AND LITERATURE

Automating business processes is not something new. Since the 1990s, companies have been trying to decide which tasks should be done by machines and which should be done by people (van der Aalst et al., 2018). Robotic automation uses set rules to imitate how a human worker does a job (Flechsig et al., 2022; Rutschi & Dibbern, 2020).

Automation began during the Industrial Revolution, when work moved from being done by hand to being done by machines. During this time, steam engines, power looms, and other machines were invented. These machines took over many jobs that used to require a lot of physical effort from people. However, these early machines were not flexible or adaptable enough for complicated tasks.

The idea of automation, as we know it now, started to develop in the middle of the 20th century. The creation of programmable logic controllers (PLCs) made it possible to automatically handle repetitive jobs and manage complicated machines. This made it possible for lots of factories to use industrial robots and computer-aided manufacturing systems, changing many industries, especially car manufacturing.

2.1 Robot

The word "robot" comes from a Czech word "robota," which means "work." This makes us think about and understand the main aim of robots in our world: to do a job or task. Since the word "robot" was first used in 1921 in Karel Capek's play R.U.R. (Rossum's Universal Robots), many different meanings for the word have been created. This is because today's robots have different uses, sizes, and jobs, so it's hard to describe them all in one way. If you ask different robot manufacturers what a robot is, they will all give different answers.

According to Collins dictionary (2022) a robot is a type of machine that is set up to move and do specific jobs by itself, or a machine that can do certain tasks on its own, similar to how a person would do them. Robot Institute of America (1979) defined robot as a flexible machine designed to move things like materials, parts, tools, or special devices in different ways to do various jobs.

According to Rodney Brooks Founder and CTO, Rethink Robotics (2018) a robot is a machine that can work on its own. It can see what's around it, make decisions based on what it sees, and do tasks in the real world.

In this article, we will adopt this definition of robot, a robot is a machine that works by itself and is designed to do tasks that people usually do, especially those that are repetitive. It can sense what's around it, think about what to do, and then take action based on its decisions. The robot is different from other machines because it can think, understand its surroundings, and work on its own. This makes it valuable and important in many industries today.

Isaac Asimov was the first to use the word "robotics" in his science fiction book "I, Robot," published in 1950. This book inspired scientists and engineers to create future robots. He was the main person who popularized the word "robot." In this book, he said:

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The three basic rules of robots are: a robot cannot hurt a person or let a person get hurt by not doing anything; a robot has to follow the commands of people unless those commands go against the First Law; a robot must keep itself safe as long as doing so doesn't go against the First or Second Laws.

In the end, Asimov said that the most important thing about how robots and humans interact is safety. If safety isn't certain, any kind of contact can happen because the main priority is always to keep people safe.

2.2 The Technological Transformation of the Manufacturing Industry and the Importance of Robots in Production Revolution

Industrial robots started in the middle of the 20th century, with the first robot, called Unimate, being introduced in 1961. The Unimate was created by George Devol and Joseph Engelberger. It was the first robot that people could buy and was mainly used to help move materials in a General Motors factory. Early robots were mainly used to handle repetitive and tough jobs in factories. This was done to make work faster and to lower the amount of hard work people had to do (Campilho et al, 2023).

In the following years, traditional industrial robots were used in many industries, like car assembly, making electronics, and producing heavy machines. These robots usually had flexible arms with many joints, allowing them to do different jobs in a safe setting.

The development of robotic arms has played a key role in the progress of robots in making things. Early robotic arms mainly used fluids or air for movement, which affected how accurate and fast they could be. But improvements in materials, sensors, and control systems have resulted in the creation of better and more accurate robotic arms (Brogårdh, 2007, Okunade *et al*., 2023).

Early robotic arms were mostly made from heavy materials, which made them less flexible and slower. Thanks to improvements in materials like light metals and strong composites, today's robotic arms are lighter and stronger. Using sensors has been very important for improving how robotic arms work. Early robots didn't have advanced sensors, which made it hard for them to adjust to changing surroundings (Feng *et al*., 2023). Modern robotic arms have various sensors, like cameras, force sensors, and distance sensors. These help them see and react to their environment very accurately. Early robotic arms used simple programming and couldn't adjust to different tasks. The development of control systems and programming languages has greatly improved what robots can do. New control methods and easy-to-use programming tools let robots perform complicated and flexible tasks, making them better at handling different jobs in manufacturing (Dzedzickis *et al*., 2021, Owebor *et al*., 2022).

Today's manufacturing methods are known for being accurate, fast, and adaptable, thanks to the development of robotic arms. These robotic arms are very important in manufacturing. They are used a lot on assembly lines, where they help put products together quickly and accurately, making sure there are fewer mistakes (Alzarok *et al*., 2020). Car manufacturing has greatly changed with the use of robotic arms for jobs like welding, painting, and putting parts together. Robotic arms can lift heavy items and work in tight areas, making them perfect for moving and storing materials. Robotic arms help make moving and organizing goods easier. They reduce the need for people to do heavy work and cut down on mistakes (Khan, 2020, Sanni et al., 2024).

Robot arms with smart cameras are very important for checking and ensuring the quality of products. They can quickly and correctly check product quality, find problems, and make sure they follow strict manufacturing rules. A big improvement in recent years is the creation of collaborative robots, called cobots, which are made to work together with people. These cobots have sensors and safety tools that let them work near people, creating a teamwork-friendly and adaptable manufacturing space (George and George, 2023).

The changes in the manufacturing industry started during the Industrial Revolution, when people began using machines to help with tasks. This made it possible to produce more goods. Over the years, new technologies like electricity and machines that work on their own helped the industry grow. The rise of computers and digital technology in the second half of the 20th century changed everything and led to what we now call Industry 4.0 (Sigov et al., 2022).

Industry 4.0 is the blend of physical and digital technologies. It combines smart manufacturing systems, the Internet of Things (IoT), artificial intelligence, and advanced robots. This change has really altered how things are manufactured, creating a production environment that is more connected, efficient, and flexible. Important parts of Industry 4.0, like data analysis and watching things in real time, are now essential for improving manufacturing processes, reducing downtime, and making better decisions (Bousdekis et al., 2021).

One of the biggest factors changing the manufacturing industry is the use of robots. Robotics has become an essential technology in Industry 4.0, changing how things are made and improving production processes. Using robots in manufacturing makes it very

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accurate when doing difficult jobs. Machines with smart sensors and devices can do tasks more accurately than traditional methods. This accuracy leads to better quality and more reliable products. Robots are really good at doing simple, boring jobs quickly and accurately. By using machines to do regular tasks, manufacturers can greatly decrease the amount of manual work needed for boring and tough jobs (Nayak *et al*., 2023). This not only makes things work better but also reduces the chance of mistakes by people. Today's robots, especially collaborative robots or cobots, are very flexible and can easily adjust to different tasks. These robots can work well with people and can be quickly changed to do different jobs. This flexibility makes the production line more responsive, allowing manufacturers to quickly adjust to changes in market needs (Lee et al., 2020). Robots help make workplaces safer by doing dangerous jobs that could hurt people. Risky tasks, like dealing with harmful materials or working in tough environments, can be assigned to robots. This helps lower the chance of accidents at work and makes the workplace safer. Robotics is not just about machines doing tasks automatically; it's also about creating and looking at a lot of data. Robots with sensors gather information right away, giving useful details about how things are made. Using data helps manufacturers find problems, improve their processes, and make smart choices for ongoing betterment (Gökalarp et al., 2021).

2.3 Quality Assurance

In manufacturing, quality usually means how well the production process follows the design plans, focusing on the different characteristics and qualities of a product (Chryssolouris, 2006). In this context, quality control is a response focused on making sure that products meet high quality standards. According to Mohamad et al. (2011), it involves three main steps: 1) checking how things are currently working, 2) comparing this performance to the desired goals, and 3) taking action to fix any gaps (Pyzdek and Keller, 2013).

Quality assurance means checking how well products or services meet quality standards. It involves actions taken to make sure that what is being made will satisfy the quality requirements (Papavasileiou et al., 2024).

Often, quality checks are done before production starts to stop problems from happening. Quality control is part of quality assurance, which is also part of quality management overall (Figure 1). In the end, quality inspection is a part of quality control. It looks at the techniques used to check products, either while they are being made or usually after they are finished, to see how good they are.

Since machines started doing the work in factories, the speed of making things went up, and checking quality became more important to prevent bad products from being sold. In robotics, quality control is important because it helps improve the product's quality in different ways, either directly or indirectly (Papavasileiou et al., 2024). There are many ways to check quality and different technologies that have been used in robots for various manufacturing processes.

Fig 1: Connections between quality management, assurance, control and inspection

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Quality assurance in manufacturing, especially with robots, is very important for many industries today. It is also a topic that scientists are interested in. This comes from earlier reviews about quality control that were published in recent years (Papavasileiou et al., 2024).

2.4 Features of Robots

Adaptive manufacturing

Robots can adjust to changes in what needs to be made. "Adaptive manufacturing" is when factories can quickly change and improve how they work based on current data, feedback, and different situations (Rana & Jani, 2023). In the field of manufacturing, this means using advanced robots and smart automation technologies to make manufacturing processes that are flexible, quick to respond, and efficient (Ashima, et al., 2021). These robots use smart sensors and learning software to transform how they work or what tools they use based on different product needs or changes in demand.

Machines that use smart technology can adjust and respond to changes in how things are made. These systems can look at past data to find patterns, learn from them, and make their own decisions to work better and simplify tasks (Hoover, et al., 2022). Robots are made to do different jobs and can be easily changed or reprogrammed to meet new product needs or production requirements (Filipescu, et al., 2021).

Predictive maintenance

Robotic systems can help prevent problems before they happen, making them more reliable and reducing the time they are not working. By keeping an eye on their health and performance, these systems can foresee problems and plan maintenance ahead of time. Manufacturing uses smart robots that have sensors to check their own condition and how well they're working (Moisescu et al., 2018). Predictive maintenance algorithms look at this data to help fix equipment before it breaks down. This helps avoid surprises and makes the equipment work better overall, making it more dependable and improving how well things run (Kahouadji, et al., 2021).

Robotic systems create a lot of data using their sensors, motors, and other connected devices. The goal of collecting and studying this information is to understand how well the robotic systems work and their condition (Bonci et al., 2019). Machine learning tools are used to find trends and unusual things in data. This helps to predict problems before they cause system breakdowns. Predictive maintenance depends on regularly checking the condition of robot parts. Sensors on different parts of the robot gather up-to-date information on things like temperature, vibration, and power consumption (Jaber, 2016). By looking at today's situation and past information, computers can find differences and predict when a part might break.

Predictive maintenance helps avoid unexpected breakdowns by scheduling repair work at the right times. Robots can work better and help produce more in factories by fixing small problems before they turn into big ones (Galbraith & Podhorska, 2021). Predictive maintenance is cheaper than the old ways of fixing things after they break or sticking to a set schedule for repairs. It helps prevent extra maintenance work and lowers the chances of expensive breakdowns. Maintenance tasks can be organized and carried out effectively, making the best use of resources and reducing costs (Tian, et al., 2022)

Autonomous navigation

Robots can move around changing settings, dodge obstacles, and find the best routes to handle materials and manage logistics in smart factories (Cohen, et al., 2019). Robots use different tools to understand what's around them, like motion sensors, radar, laser sensors (LiDAR), and cameras. Data from multiple sensors is put together using sensor fusion methods to create a full understanding of the surroundings (Nagy & Lăzăroiu, 2022). Computer vision programs help robots understand what they see, identify items, and move around by analyzing pictures or videos (Nagy & Lăzăroiu, 2022).

Robots can figure out where they are and what's around them at the same time using special methods called simultaneous localization and mapping. This is important for finding their way in changing surroundings. Advanced methods for finding a robot's location, like Monte Carlo Localization (MCL) and Kalman filtering, help to determine the robot's position accurately (Emmi, et al., 2021). These algorithms help robots find the best path from one place to another without hitting anything in the way. As a result, the robots can navigate their work schedules by dodging obstacles and finding better paths while they work (Hofmann, et al., 2019).

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Fig. 7: Flexible Manufacturing System with smart robots.

Quality control and inspection

Quality control and inspection are very important for making sure that robots work well and can be trusted in manufacturing. Robot systems with smart cameras help make high-quality products by carefully checking and inspecting them consistently. They can find problems, check measurement, and make sure everything meets quality rules (Ammar et al., 2022). Robots have tools, like cameras and sensors, to gather information while making products. These sensors give details about the quality of materials used, products made in between, and the final product, helping to ensure overall quality control.

Advanced data analysis and machine learning are used to look at the collected information to find patterns, unusual things, and potential problems. Using machine learning models can help make the manufacturing process better by predicting and preventing problems (Klinhgenberg, et al., 2021). Robots can use cameras and image processing to automatically check and inspect products. Robots with cameras can spot problems, check sizes, and make sure products are of good quality.

Digital twin integration

Digital twins create virtual versions of real-life robotic systems. This includes detailed pictures of the entire factory and the different robots and their parts (Groshev, et al., 2021). These digital models are constantly updated with live data from the sensors on the actual robots, giving a correct and current view of the system.

Digital twins allow us to watch robotic systems in real time. Robots have sensors that gather information, and this information is sent to the digital twin to be analyzed. Analytics tools analyze this data to find patterns, unusual occurrences, and performance measurements. This helps in predicting maintenance needs and improving how robots work (Pires, et al., 2019).

Before making changes or upgrades to the real robotic system, digital twins let us test and simulate everything in a virtual setting. This helps to find problems, improve processes, and make sure changes will work as intended without disrupting real production (Azarian, et al., 2020). Digital twins are used to keep track of robotic parts all the time (Soori, et al., 2024), this helps predict when they need maintenance. Predictive maintenance helps fix potential issues before they turn into big problems. This reduces the time robots are not working and makes them more reliable.

Energy efficiency in intelligent robotic systems

Robots help make factories use less energy, they do this by moving efficiently, minimizing wait times, and using energy-saving tools. Robots focus on saving energy and being environmentally friendly (Mohamed, et al., 2019); using less energy in robots helps the environment, saves money, and makes things work better overall (Demir & Sarı, 2020). By making movements more efficient, cutting down on waiting times, and using energy-saving options, these systems help to create eco-friendly manufacturing practices (Teng, et al., 2021).

You can create robotic parts that use less energy, like motors, sensors, and processors. You can choose robot parts that work really well but use less energy, like energy-efficient processors and sensors, without losing any performance (Wolniak, et al., 2020), this

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is especially important for robots working in different settings (Rahman, et al., 2019). We can use energy-gathering technologies, like solar panels or devices that collect energy from movement, to help or replace regular power sources (Hawari, et al., 2021).
We can use motion planning methods that cut down on unneeded movements and improve paths to save energy (Badada et al., 2020). Adaptive control algorithms can change how a robot acts based on current information and the surroundings. This helps the robot use energy more efficiently while it works. We can use predictive maintenance tools to find possible problems in robots before they cause them to use too much energy (Massaro & Galiano, 2020).
Selective sensing can be used to turn on sensors only when they are needed, which helps save energy (Soori, et al., 2024). Doing data processing and analysis near where the data is created (edge computing) can help reduce the energy needed to send a lot of data to a central system.

2.5 Types of Robots

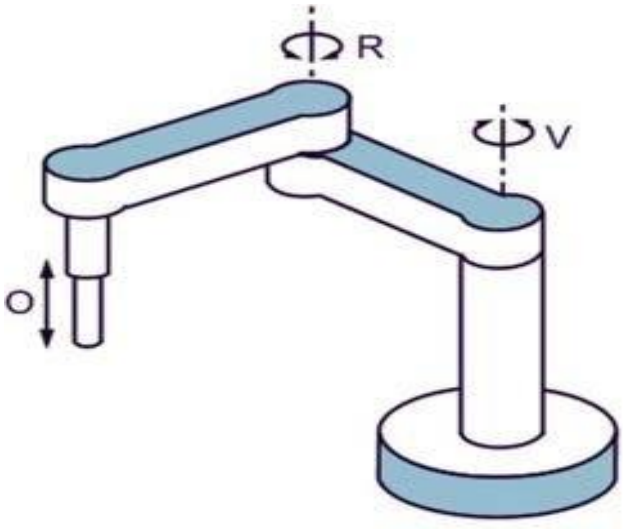
There are different kinds of robots used in factories, and each one is made for specific jobs and tasks. Here are some usual kinds of robots used in factories:

Articulated Robots

Articulated robots are the most common type used in manufacturing. They have several turning parts that copy how a human arm moves. This flexibility enables them to do many different tasks accurately and skillfully. Articulated robots are often used for tasks like welding, binding things together, moving materials, and painting.

SCARA Robots

SCARA robots are built for fast and accurate assembly work. They can move their arms up and down, as well as side to side, and they are good at moving quickly and hitting the right spots. SCARA robots are often used for coupling electronic parts, moving items around, and packing things.



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Cartesian Robots

Cartesian robots, also called gantry robots or linear robots, move based on a simple grid system that has three straight lines (X, Y, Z). They provide high accuracy and can be used repeatedly, making them great for tasks that need exact movements in a specific direction. Cartesian robots are often used for moving materials, stacking items, and picking up and placing things.

Delta Robots

Delta robots have a simple design with three arms that are all connected to the same base. They are very good at fast jobs that need quick and accurate movements, like packing, sorting, and putting together small parts. Delta robots are famous for being fast and effective.

Collaborative Robots (Cobots)

To keep people safe and prevent accidents, industrial robots need to work away from human workers while doing their tasks. This means the robot needs a space where people can't go while it is working, or it has to reduce its power and abilities to work safely in a space where people are present. Unfortunately, this is a problem because it restricts what the robots can do.

The increasing need for machines to do tasks, along with the benefits of working with robots, has led to the creation of Collaborative Robots. These robots can safely work alongside people without putting them at risk. The word "Cobot" is short for "collaborative robot." The IFA (Institute for Occupational Safety and Health of the German Statutory Accident Insurance) describes Cobots as advanced machines that work alongside people. In a shared work process, they help and make things easier for people. Simply put, it's a robot that works together with humans in the same space to reduce their workload.

An interesting study about Cobots was done by Forbes magazine. It says that Cobots are like the physical version of the smart software technology we often talk about. Instead of taking over jobs from people, Cobots help humans by giving them extra strength, accuracy, and data skills. This allows people to do more work and bring more benefits to the company (Forbes, 2019)

Cobots are robots made to work safely with people in the same area, without needing walls or barriers between them. They have sensors and safety features that make it safe for people and robots to work together. Cobots are used for jobs where people need to work together, like putting things together, helping machines, and checking quality.

These robots can work together with people to make work environments more adaptable, safer, and more productive (Tantawi, et al., 2019). Collaborative robots are made to work together with people in the same work area. When people and robots work together, industrial processes can adapt better, allowing each to use their strengths effectively (Yavuz, et al., 2023). Cobots can

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work safely close to people without needing fences or barriers. This allows for a more flexible and responsive production space (Kumar, et al., 2020).

In Industry 4.0, there is an increasing demand for manufacturing systems that can easily change and adjust. Collaborative robots are made to be easily changed and used in different ways. This helps manufacturers adjust to new needs in production or changes in the products they make (Buhl, et al., 2019).

Cobots have special sensors and technologies that help them see and feel things, like cameras and sensors that measure strength and pressure. These features help them see their surroundings, identify things, and respond to changes quickly. This improves their ability to work safely with humans (Bi, et al., 2021). Cobots are designed to help people, not replace them. They can do tasks that take a lot of time or are done over and over again, which allows human workers to spend their time on more important jobs that need creativity, thinking, and solving problems (Soori, et al., 2024).

Mobile Robots

Mobile robots can move by themselves or with some help. They can find their way around and work in places that change a lot. They can move around easily in a factory, doing jobs like moving materials, managing stock, and cleaning the floor. Mobile robots often use sensors and mapping tools to help them find their way.

Vision-Guided Robots

Vision-guided robots use cameras and special computer programs to see and understand what is around them. These robots can find objects, see where parts are, and do jobs by looking at what they see. Visionguided robots are often used for checking quality, picking up and moving items, and putting things together.

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These are just some examples of robots used in factories. Every type of robot has its own benefits and uses, and the type chosen depends on what the manufacturing job needs.

2.6 Applications of Robots in Manufacturing

There are many uses for robots in factories, and new ones are being created all the time. The manufacturing industry uses robots a lot, especially in car making and assembly lines. These robots help with many jobs, such as picking, packing, stacking boxes, welding, assembling, moving materials, checking products, and more (Sherwani, 2020). The changing market and customers' high demands make it challenging for the industry to be more efficient and adaptable. Robots are now being used in manufacturing not just for assembly and simple jobs, but to work alongside humans in nearly all production and non-production tasks.

In the literature, we found many different applications of robots in manufacturing. Here's an outline of those uses:

- Welding
- Material handling
- Machinery
- Assembly
- Quality inspection
- Picking, packing, and palletizing
- Automative

To explain them clearly, table 5 shows a short description of each application, a summary of its main benefits, and the sources where this information was found.

Table 1: Human-Robot collaboration applications in manufacturing systems

Application	Brief Definition	Benefits	Document
Welding	Welding robots can do welding very accurately and quickly by themselves. They can also help human workers with welding when needed. The robot can see, program itself automatically, guide, track, and control the welding process intelligently in realtime. Since we're discussing a teamwork system, it helps deal with complex and uncertain situations by using people's skills. The robot is designed to be used as a tool and has very little ability to think or act on its own.	Precision Repetitiveness	Sherwani, 2020, Villani, 2018, Vojic, 2020

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Material handling	Moving things inside a factory is hard work for people. Using robots to move materials is helpful because it lessens the strain on workers when lifting and moving heavy items. Robots are also useful when materials are too dangerous, dirty, or heavy for people to handle safely. It's important to note that it doesn't suggest that the human worker should collaborate; instead, it implies working together. The robot is designed to be used as a tool, so most of the thinking needed depends on the person using it. There are many different types of palletizing and material handling robots on the market. They can lift different weights and have various tools, such as bag grips, suction cups, and magnets.	Quickly move things to where you want them. Better health and safety for workers Lowered expenses Quicker making processes Less time not working	Grau, 2021, Villani, 2018, Vojic, 2020, Sherwani, 2020
Machinery	Using robots as machines means thinking of robots • as tools. In welding jobs, they can do these tasks • very accurately and quickly by themselves, and they can also help human workers. Cutting, smoothing rough edges, making holes, metal casting, grinding down, taking away material, shaping, shining, filling up with fuel, guiding, rubbing down, spinning tool, and using water jets.	Precision Repetitiveness	Grau, 2021
Assembly	Robots help make factories work better and have improved how things are made. It follows what's known as hybrid assembly robotic cells. Robots can pick up parts quickly and put them together. This helps workers by letting them focus on more important tasks instead of doing boring jobs. As a result, workers can be more productive with simple assembly tasks. Cooperative assembly workstations are designed for step-by-step assembly. Robots handle easy tasks first, while human workers do the more complex and varied tasks at the end to add unique features to the products. The timing and teamwork between people and robots are very important. They can greatly impact how well human-robot collaboration is accepted and how effective it is.	Makes putting parts together faster and more accurate. Making sure things are safe and comfortable to use. Better quality, more reliable results, and faster production. Simple programming makes it quick to set up new assembly configurations. Takes up less space, easy to carry, and lightweight. Making things easily adjustable Can adjust production to handle busy times and changes in what customers want. Quick return on investment	Vojic, 2020, Sherwani, 2020, Berglund, 2019, Villani, 2018

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Quality inspection	A robot arm does tasks exactly the same way every time, with very few mistakes, and is much more accurate than a person. It can do this boring job very well without getting tired or bored, unlike people. The most common use is to combine a camera system with a robot. This setup allows us to check products for quality and quickly remove any faulty ones from the production line. The main goal of the camera is to find and take out any broken parts before they are packed or sent out. Using human-robot teamwork for checking quality helps to lower mistakes made by people and creates a new way to ensure products meet standards for customers.	Accuracy and reliability Lower running expenses Reliable quality	Vojic, 2020, Sherwani, 2020, Berglund, 2019
Picking, packing, and palletizing	Businesses need more and more packaging. Nine out of ten packaging companies are now using robots. Doing these tasks by hand can be boring, very hard work, and take a lot of time. Robots can help with shrink-wrapping, putting boxes together and loading them, and organizing boxes onto a pallet for shipping.	Quickness Robots can work for a long time, even for days.	Vojic, 2020, Sherwani, 2020, Berglund, 2019
Automotive	A separate category is made for cars because both businesses and universities are very interested in this area. It's important to note that most of the uses for these robots are for assembly jobs, where they work alongside people on production lines. Robots help make high-precision tasks more accurate, which is very important in this industry.	Making sure parts fit together quickly and accurately. Better quality, more consistent results, and faster production. Easy coding for quickly setting up new assembly layouts. Saves space, is light, and made easily. Flexibility.	Villani, 2018

These are some common areas where robots are used. Nowadays, businesses are starting to use these robots in various situations because they are flexible and can be used in many ways.

2.7 Empirical Literature

Wang and Wang (2018) gave an in-depth look at how robots are used in smart manufacturing. Their study talks about combining robots with new technologies like the Internet of Things (IoT) and Artificial Intelligence (AI) to improve how things are made in factories. The review looks at different ways robots are used in tasks like automation, assembling, moving items, and checking quality.

Leitão and Colombo (2016) conducted a study which looks at how smart robots are used in factories and other industries. Their research looks at how robots can help increase productivity, improve the quality of products, and make manufacturing processes more flexible. The review shows how combining robots with advanced control systems, machine learning, and vision technology can improve the performance and flexibility of manufacturing systems.

Duan, et al. (2020) assessed how robots affect work speed, jobs, and employment in factories. Their study talks about the pros and cons of using robots, like how they can boost productivity, cause some people to lose their jobs, and create a need for workers to learn new skills. The review looks at different case studies and shares thoughts on how using robots can affect the economy and society.

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Ribeiro, et al. (2019) assessed how robots are used in factories and workplaces. Their study looks at where robots are used, such as making products, putting things together, moving materials, and checking quality. The review talks about how robots work with other technologies like sensors, artificial intelligence (AI), and communication networks to build better manufacturing systems.
Chen et al. (2017) conducted a survey to assess how people and robots work together in factories. The study looks at how robots help people work better, stay safe, and feel more comfortable. The survey talks about the problems and possible answers for getting people and robots to work well together in making things.

3. METHODOLOGY

The method used for this study were based on a review of academic articles and supported by theory. A thorough study was necessary for this research because the main goal of the paper was to create new understanding based on the collection of a lot of information. This research paper looked at how robotic automation works with AI and how it can be used to automate manufacturing tasks. This study uses qualitative research methodology (Becker et al., 2012). So, we used a search plan to find as many useful articles as we could by using different keywords and data sources. The research used specific words to find details about the main topic, "Integration of Robotic Automation in Manufacturing: Benefits and Challenges of Quality Assurance". This was done by linking it to other related words like integration, business process, and intelligent automation. So, we found academic information and publications by looking through different online databases to create the datasets.

3.1 Data Sources and Searches

The articles were gathered from January 2014 to December 2024, and they were only in English. The search terms used to find relevant research were: ("Robotic Automation," "Bots," or "Robots") along with ("manufacturing" or "industry") and ("quality assurance"). This was done in different ways to make sure only the right information was included.
The information was taken from several databases listed below:

1. Scopus (https://www.scopus.com)
2. Web of Science (https://www.webofscience.com)
3. Business Source Premier (EBSCO) (http://search.ebscohost.com)
4. ABI Inform - Proquest (https://about.proquest.com), and
5. Google Scholar (https://www.google.com)

In the literature review, the authors arranged each article using color codes and tags (Knafl, 1998). The study was well planned and carried out, and the way results were reviewed and managed was well organized for this kind of research, as noted by Knafl (1998).

3.2 Study Selection

From the beginning, we looked at trusted journals and online sources that talked about using robots and AI for automating business tasks. The papers were gathered after a thorough check that confirmed the data and datasets based on their title, keywords, abstract, and their submission and publication in academic journals and databases. We collected 53 potential journals for review that focus on integration of robotic automation in manufacturing, leaving out any publications that weren't relevant.
The authors carefully read and approved the abstracts and conclusions of the 53 papers they found. They organized this information using methods like color coding and tagging (Knafl, 1998). So, all the articles were sorted and organized by their title or theme, and then we looked at how they fit into each category. After going through many reviews, we looked closely at 39 journals that met the important requirements. Figure 1 shows the steps and rules used in this study.

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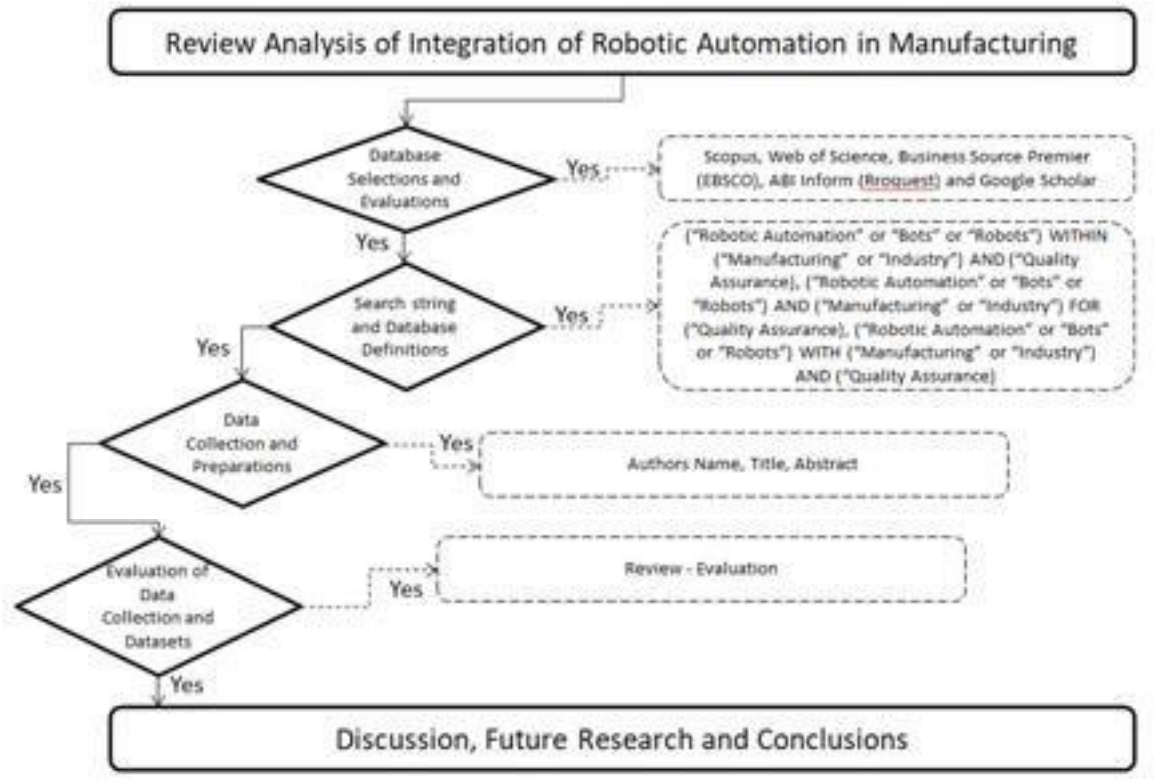

Fig. 1: The flowchart of stages involved in the methodology

4. INTEGRATION OF ROBOTIC AUTOMATION IN MANUFACTURING

4.1 Proposed Technique for Integrating Robots

These ways can be used to effectively integrate robotic automation into any manufacturing company:

1. *Identify Manufacturing Processes*: Start by looking for the manufacturing processes in the industry that could use robots to improve. This may involve jobs like assembling, welding, moving materials, packing, checking items, and ensuring quality.
2. *Examine Process Needs*: Carefully look at the chosen manufacturing processes to understand what is needed, like how much automation, accuracy, speed, and flexibility is wanted. Think about things like how different the products are, how long it takes to make them, the quality needed, and safety issues.
3. *Evaluate Robotic Applications*: Check out different robots and technologies that fit the manufacturing processes identified. Think about things like the type of robot, how much weight it can carry, how far it can reach, how fast it moves, how accurately it works, and what senses it has. Evaluate how well different robot models meet the needs of the task.
4. *Create a plan for the robotic work area*: Think about how everything is set up, how easy it is to use, and how the robot will work with other machines and tools. Make sure the workcell design helps the work flow smoothly, reduces the movement of materials, and keeps both people and robots safe.
5. *Programming and Control*: Create the programs and control systems needed for the robots. This might mean creating instructions for how a robot moves, plans tasks, and works with other machines. Think about using programming languages, software made for robots, and ways for people to interact with machines to control and operate them well.

4.2 Steps for Integrating Robotic Automation in Manufacturing

Many researcher have worked on creating the concept of a robotic automation life cycle (ChacónMontero et al., 2019; Yi-Wei et al., 2019). They broke it down into these steps: analysis, design, development, deployment, testing, and monitoring. Figure 3 shows the steps in the robotic process automation life cycle.

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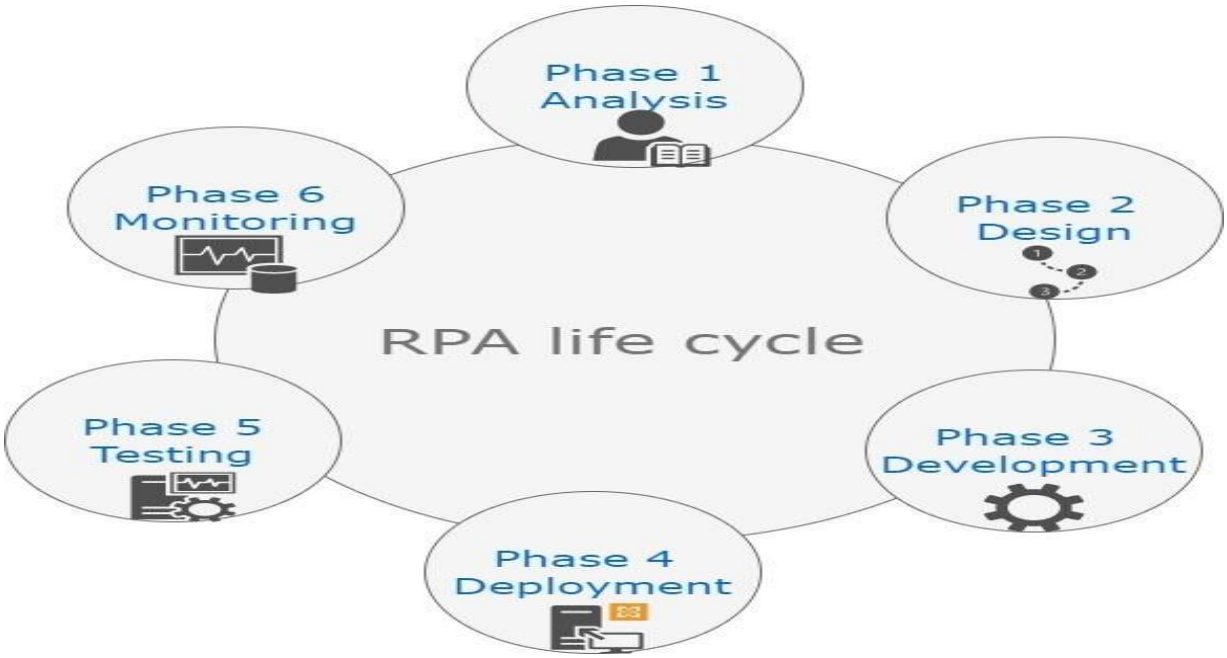

Yi-Wei et al. (2019) a similar model was created about the steps in the robotic process automation (RPA) life cycle. These steps include planning for RPA, figuring out what is needed, designing the RPA process, implementing it, testing it, operating it, and maintaining it. This research study uses the robotic process automation cycle created by Chacón-Montero, et al. (2019), the stages of robotic process automation life cycle were explained as follows:

Analysis Phase

The first step is to choose and sort the right tasks to automate. This means looking at how work is done now and finding tasks that happen over and over again and can be done by robots. Next, we need to decide what tasks will be automated. This means figuring out which systems should work together and setting the guidelines for what the robots can do (Chacón-Montero et al., 2019). Third, you need to pick a robot that fits the described needs and features. The selected robot should be user-friendly, and compatible with the current or old systems that the organization uses.

Design Phase

The purpose of this phase is to explain and look closely at all the steps needed to create workflows, activities, and design patterns, as well as to outline the tasks that will be done in the robotic automation process.

Development, Deployment, and Testing Phase

The robotic process automation system is created and tested in a safe setting. Now, we need to choose between two methods: the traditional waterfall model or the agile approach. Yi Wei et al. (2019), a specific solution was proposed by looking at how the two methods work in real-life situations.

Next, the created process should be checked to see if it meets the needs outlined earlier. After that, the solution should be tested to make sure it works correctly (Chacón-Montero, et al., 2019). After the robotic automation solution is built and tested, it is put into use in the real environment. This means putting the robots in factories that will do the work automatically and setting them up to run quietly. After the robotic automation system is set up and running, it's important to teach employees how to use it. This helps them feel confident and comfortable working with the new system.

Monitoring Phase

After that, the robotic automation needs to be watched and taken care of to ensure it keeps working as planned. This means watching how well the robots are doing, finding and fixing any problems that come up, and replacing or maintaining the robots when necessary (Chacón-Montero et al., 2019). As the factory becomes more skilled and confident with robotic automation technology, it can increase and broaden its use to automate more tasks and improve efficiency.

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So, using robotic automation in a production setting needs careful planning, testing, and checking to make sure it works well and is successful.

4.3 Benefits of Integrating Robotic Automation in Manufacturing

Robotic automation is a technology that doesn't harm current systems (Madakam et al., 2019). It works with what is already in place without needing any changes, making it affordable to use (Asatiani & Penttinen, 2016; Engel et al., 2022). Compared to other automation options, robotic automation is cheaper to start using, takes less time to set up, and is inexpensive to maintain in the long-run. This helps organizations save money on their overall IT costs (Asatiani & Penttinen, 2016; Fung, 2014).

Cost-Savings

After using robotic automation, businesses will save money on employee costs. Some studies say that robotic automation can reduce these costs by 20% to 50% (Syed et al., 2020), while others say it can cut them by as much as two-thirds, compared to having humans do all the work. The numbers are about robots taking over the jobs of full-time workers. One full-time worker (FTE) is the same as one person doing a job full-time (Asatiani & Penttinen, 2016; Syed et al., 2020).

Asatiani and Penttinen (2016) say that robotic automation could be a different option to traditional outsourcing for tasks that are not central and are done repeatedly. Both options can lower costs related to workers and allow companies to concentrate on what they do best. However, outsourcing can have hidden costs and complicated contracts to manage. On the other hand, robotic automation avoids these issues and still provides benefits (Asatiani & Penttinen, 2016; Fersht & Slaby, 2012; Madakam et al., 2019). Robots can work all day and night without stopping and they cost less than humans (Driscoll, 2018; Fung, 2014; Syed et al., 2020); this can help improve how much work gets done (Asatiani & Penttinen, 2016).

Saving money is one benefit of becoming more efficient by using robots to automate processes. Other ways to measure efficiency are saving time, reducing manual work, and getting more done. These factors work well together because when we have fewer manual tasks, we save time. This means less waiting time and quicker task completion. According to Syed et al. (2020), using robots to automate tasks can make operations work better. This includes saving money, taking less time, and needing fewer people to do manual work. These advantages are seen as important reasons for organizations to adopt robotic automation. Business leaders also view it as a smart way to improve important performance measures (Fung, 2014; Gotthardt et al., 2020; Hofmann et al., 2020; Januszewski et al., 2021; Leshob et al., 2018; Syed et al., 2018).

Reduced Manual Workload

Less manual work is thought to help staff by letting them move away from boring, repetitive tasks to more interesting and important work (Hofmann et al., 2020; Leshob et al., 2018; Syed et al., 2020). This change is believed to boost employee morale (Madakam et al., 2019). When skilled workers are given more interesting and engaging tasks, it helps improve efficiency (Madakam et al., 2019; Syed et al., 2020).

In the next 30 years, about 76 million baby boomers will stop working, but only 46 million new workers will be ready to take their places. During this time, industries will keep needing workers, so using machines to do the work is a good option.

Accuracy and Quality

Using robots instead of humans helps companies do better work and be more precise (Driscoll, 2018; Rutschi & Dibbern, 2020). Tasks that involve moving between different computer programs and transferring data from one place to another are suitable for automation with robots. These tasks can also easily have mistakes (Fung, 2014). Das and Dey (2019) say that robotic automation can reduce mistakes made by humans if everything is done correctly. Also, Syed et al. (2020), said that using robotic automation reduces human mistakes, and tasks done by robots are likely to be completely accurate. Also, Fung (2014) and Madakam et al. (2019) noted that using robotic process automation can lead to more accurate results and fewer mistakes, but they did not provide specific numbers showing how much it improves. Robots can work faster and more accurately than people and don't get tired. This means they can do some tasks better than humans (Costa et al., 2022; Rutschi & Dibbern, 2020). One benefit of using robots instead of people is that you can quickly increase or decrease their capacity depending on how much work needs to be done. This means the amount of work robots do can easily change based on the company's needs (Das & Dey, 2019; Fersht & Slaby, 2012; Hofmann et al., 2020; Syed et al., 2020).

Hassle-Free to Set Up

Another advantage of robotic process automation is that it's easy to set up, and you don't need to know how to code (Lacity & Willcocks, 2016a; Madakam et al., 2019). Companies that provide robotic automation offer a user-friendly interface, allowing you

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to create automations by simply arranging different parts to follow your business rules and logic (Hofmann et al., 2020), this lets the people in charge of business processes create the automation by themselves. The automated processes can be used by more than one business, and the people in charge can use the same methods they created before (Hofmann et al., 2020). Lacity and Willcocks (2016b) say that people who don't work in IT can learn to use robots in just a few weeks. This helps to get things done more quickly (Osman, 2019). The business team can still manage the process, which means they don't rely too much on the main IT department (Fersht & Slaby, 2012). When control of business tasks is moved from people to robots, it leads to better overall management (Syed et al., 2020).

Better Workplace Safety

Automation improves workplace safety by taking over risky tasks and reducing how much workers have to be in dangerous situations. By having machines with safety tools handle risky jobs, manufacturers can lower the chances of accidents and injuries at work, which helps keep employees safer and healthier.

In many situations, robots help workers by taking over boring tasks that can lead to errors and health problems (Matheson et al., 2019). Production lines in various factories need constant attention, which is tough for people to do all the time. Human mistakes not only cause loss of products but also can be dangerous for workers and their teammates.

Automation tools like robotic arms can be set up to do risky and tiring jobs, helping to keep workers safe. Thanks to robots, workers no longer have to work in dangerous places or tough conditions like hot and dusty factories.

Many sources mention that using robotic automation helps make manufacturing better by improving its accuracy, consistency, compliance, and security (Fung, 2014; Januszewski et al., 2021; Leshob et al., 2018; Siderska, 2021).

4.4 Quality Control in Manufacturing through Robotic Automation

Quality is very important in today's market. Organizations need to make sure that customers get products that meet the right quality standards. No matter what kind of business it is or what they make, they all need to make sure their products meet the required standards. ISO 9000 explains that quality means how well a company's products and services meet customer needs and the effects they have on people who care about them, whether those effects are planned or not. The quality of products and services means not just how well they work, but also how valuable and helpful they seem to the customer.

To make sure the product is up to standard; we need to set up quality checks and inspections during the manufacturing process. The more uniform these controls are, the quicker and better the process will be. In today's factories, there are two main types of inspections: online and offline. They are described like this:

- Online inspections happen while the product is being made, during the manufacturing process. This type of check is mainly used when products are being made continuously, when the rules are very strict, and when it's important to find problems quickly. This way, we can fix the problem and cut down on delays and extra work on parts, if we can. If not, all products will not meet the requirements and can't be fixed, leading to a big loss. This way, we can ensure that the quality and the standards are being kept throughout the production process. These features make online inspections more convenient and cost-effective, but they can't be used for every type of manufacturing process. That's why a second type of inspection, called offline inspection, can be done (Genta, 2020).
- Offline inspections happen after the product is finished, but they can also take place at different steps during manufacturing, which means checking the semi-finished product. The benefit of this type of control is that it doesn't interfere with the production process. However, any problems with the product will only be found at the end, which means that if the product can't be fixed, all the work and materials put into it will be wasted, resulting in a loss for the company (Genta, 2020).

The type of inspection chosen, how it is carried out, and how it is managed and updated will determine if the entire production process runs smoothly or if problems and errors make the manufacturing process costly and inefficient. Nowadays, markets have high demands, which forces businesses to be more adaptable and quickly make a variety of products. This is known as mass-customization. As a result, this makes it harder to create a clear, consistent, and mistake-free inspection process.

Using robots in quality control has become more important in recent years because they help solve the challenges we face. Robots are easy to use, fast, and can work well with people. An important feature of robots for inspection is that they can do the same task over and over with precision. They can do the inspection process as many times as needed, without stopping, all day and night. They will do it the same way each time, which discover problems better. These types of tasks are often done incorrectly by people,

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which is why it's exciting to have robots help out. This also means that workers will feel more motivated because robots will handle repetitive and automatic tasks. This way, people can concentrate on more interesting work that requires human thinking.
For example, most applications use a robot with cameras or sensors. These robots can check different visual features like size, shape, and if an issue is present, all with high accuracy.

Figure 7. Optical system for quality inspection – experimental setup (Papavasileiou et al. 2021)

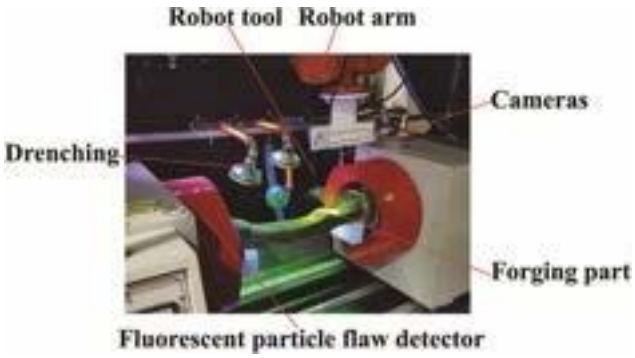

Figure 14. Physical system used for robotic fluorescent magnetic particle inspection (Wu et al. 2023)

4.5 Analysis of Real-Life Examples

The main goal was to find real examples, so we decided to visit the websites of robot makers. In this research, the official page of Universal Robots was discovered. Universal Robots has been working in the robot industry since 2005 and is a leader in this field. However, they didn't sell their first collaborative robot until 2008. Their website has a lot of information. Unlike their competitors, they have a whole section with case studies that show how their robots are used in real life, often including videos.

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Company	Solution	Main Benefits	Technology Used for Control	Type of Quality Control	Type of Inspection	Robot	Humans	Robot	Humans
BW Industrie	A robot shows metal tubes to two high-quality cameras that check the size and shape of the tubes. If the inspection fails, the robot puts the part in a box for rejected items.	• Stay competitive and grow the number of employees by 50%. • Income went up by 70%. • Lowering the chances of muscle and joint problems in workers, making the workplace healthier. • High return on investment in less than a year.	High-definition cameras	On-line	Dimensional Measurement	Single	Single	Active	Supportive
Böco Böddecker	The UR robot marks and labels items according to strict rules while checking their quality. The robot uses a camera to find and get rid of bad parts. The camera can clearly	Decreases the chance of sending broken parts to customers.	A robot arm with six moving parts that can lift up to five kilograms. Sophisticated camera control system.	On-line	Visual	Single	-	Active	Supportive

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	check how good the part is.								
Comprehensive Logistics	The robot moves a camera carefully and accurately to different inspection spots, taking a picture of each connection. If the inspection doesn't pass, the operator can go back and check only the part that failed. Every picture is looked at, and the results are displayed on a screen next to the robot.	• Return on investment in 7 months. • Perfect quality in making car engines. • No need for maintenance, and no stops or interruptions in the production line.	Vision camera	Off-line	Visual	Single	0	Active	Inactive: robot arm Automatically stops operating if it encounters objects or people within its route.
Craft and Technik Industries (CATI)	A robot puts a part on a scale, checks the weight using digital signals to see if it	Efficiency has improved as production has increased by 15–20%, with no mistakes or	Weighting machine	Off-line	Weight Measurement	Single	0	Active	Inactive

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	matches what is needed, and then sorts the part based on that.	rejected products from customers.							
		40,000 pieces, with no mistakes or complaints f rom customers.							
EVCO Plastics	After the cap is put on correctly, the UR5 puts the gearbox on a scale to check that the grease has been added. If the gearbox is too heavy or too light, the UR5 puts it in a reject box. Just like the UR5 in the assembly area, the UR10 on the packaging line also uses force and torque sensing. It first checks that all four corners of the box are	Total costs are spread out among many customers, which makes prices very competitive.	-	Off-line	Weight Measurement	Single	0	Active	Inactive

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	in the right places. Put cardboard sheets between each layer of parts in the box.								
Ford Motor Company	Looking at the engine with a UV light and a camera to find any leaks after adding oil.	Quicker production and less boring work for employees. Cobots only need help from people when something in the usual processes changes.	The Cognex camera, a UR+ product, is talking to the Cobot using an Ethernet connection.	On-line	Visual	Multiple	-	Active	Supportive: Cobots do not require human/operator's intervention unless a
GKN Automative	Two UR5 robots were added to check the front and back of a thin iron plate. An outside camera checks if the plate is on the correct side or not.	Making things 24 hours a day. A safe way to save space. No more chance of workers getting tired.	Outside high-quality camera Zone sensors are placed in four directions. They make the robot move more slowly when people are nearby.	Off-line	Visual	Multiple	Single	Active	Supportive
El-Izo M.C. D.O.O	The first project involved two	A robot can work for eight	-	Off-line	Conformity /	Single	0	Active	Inactive

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	tasks where the robot was used to	hours in a row, all the time			functionality				
	test low voltage and medium voltage surge arresters as part of their regular product checks. In the future, we plan to test the strength of tension composite insulators and post line composite insulators regularly.	□doing the job □well. Making and testing each product takes less time, which lowers the overall production cost because mistakes made by people are avoided. Return on investment (ROI) will take 18 to 24 months.			test				
Koyo Electronics Industries	When UR3 uses the stylus on the touch panel, "OK" shows up if everything is good, and a green light on the signal tower turns on. When something unusual is found, "NG" shows up on the screen, the red light tower turns on, and the buzzer keeps making noise. So, the person in charge quickly sees	□The work got □better. □Keep production □running □smoothly. Cut the daily work time from about 10 hours to 8 hours. 31% more work done. A return on investment (ROI) in just one year. Moving workers to a different task.	Stylus	Off-line	Conformity/ Functionality Test	Single	Single	Active	Supportive

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	the problem and can take action.								
Nordiczucker	The UR5 robots read barcodes and pick up containers of sugar for testing, moving them from the scales to filters and then back.	You don't need to call costly experts anymore when you want to change what a robot does. Time to pay back: 124 days.	Barcodes scanner	On-line	Weight Measurement	Multiple	0	Active	Inactive
Optipro Systems,	When parts are made by an OptiPro grinding machine, the QSpan® Workstation quickly checks them to see if they are good or not. If the parts are okay, they go to the CMM machine for more measurements.	Find any problems immediately and adjust the drills or speed if needed. Prevent fragile materials from breaking and sharp edges from chipping or cracking when handled by workers. Reduce the	-	On-line	Dimensional Measurement	Single	Single	Active	Supportive
		number of workers in the facility.							

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Stellantis	Check visually to make sure the adhesive band is applied correctly around the edges. Also, measure the softtop frame to confirm its size. The vision system looks at the shape and size of the adhesive band to make sure everything is smooth and correct. The UR robot checks the size of the soft-top frame using a camera system to make sure it is correct. Matching the sizes. After checking that everything is correct, the robo t takes the soft-top off the line.	We improved the accuracy and quality of work and made it easier to do tasks that were done by hand before.	-	On-line	Dimensional measurement	Multiple	-	Active	Inactive

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Thryssenkrupp Bilstein	Check the gauge and make sure the crimp and final parts are put together correctly after filli ng. The robot used in the final assembly has a Cognex camera and quickly moves betwee n inspection spots to check that all parts are in the correct place and that the label is on right and can be read easily.	Return on investment in 10 to 14 months. Product quality improves with complete inspection. No maintenance needed, and no breaks or stops in production. Getting rid of repetitive and uncomfortable work processes. Workers relieve d from uncomfortable jobs.	-	Off-line	Visual	Single	0	Activ e	Inactive

Challenges and Opportunities for Quality Control

Overall efficiency and costs reduction

Using robots for quality control has made manufacturing lines work better and has lowered costs. The return on investment (ROI) for robots is looking good, usually taking from a few months to at most two years.

Some of the phrases that support what was said before can be found in the Universal Robot applications section.

- The Cobot is flexible, which helps share costs among many customers, making them very affordable.
- "Manufacturing under a full 24-hour operation."
- "31% increase in productivity."

Reduce human error

Another advantage that all industries experienced by using robots for quality control is that they made fewer mistakes, which led to more accurate detection of defects and fewer rejected products from customers. Some of the phrases that support what was mentioned before can be found in the section about Universal Robot applications.

- "Reduces likelihood of faulty parts being sent to customers."
- "100% quality in the assembly of automotive engines"
- "Efficiency has increased with production volume going up 15–20% with no defects or customer rejections."
- "40,000 parts, with zero defects or customer rejections."

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- "The production and testing time of each product is much faster, reducing the overall production cost as human errors are eliminated."

It's very important to lower the number of mistakes and improve the ability to spot defects in quality control for manufacturing processes. To stay competitive, we need to think about how we can make things better using teamwork.

Figure 15: Manufacturing defects that robotized cell intends to prevent using liquid penetrant examination (Castro et al., 2017)

4.6 Challenges of Integrating Robotic Automation in Manufacturing

A coin has two sides, and robotic automation also comes with risks and challenges along with its benefits (Lahtinen, et al., 2023). Using robots in manufacturing brings new possibilities but also some problems (Tidd and Bessant, 2020).

Suitability for only Specific Tasks and Processes

One main problem is that robotic automation can only be used for certain jobs and tasks (Asatiani & Penttinen, 2016; Fernandez & Aman, 2021). Finding the right processes for robotic process automation needs special skills and the right method, which can be quite difficult (Fernandez & Aman, 2021; Siderska, 2020). When starting with robotic process automation, it's important to choose simple tasks that are easy to automate. Avoid complicated or personal tasks at first. This approach can help reduce risks. Robotic automation is a new technology that hasn't been tested as much as traditional outsourcing (Asatiani & Penttinen, 2016). This makes it difficult for organizations to decide the best way to assess their tasks (Costa et al., 2022).

Data Security and Privacy

Fernandez and Aman (2021) say that data security and privacy are the biggest concerns with robotic automation. However, other studies (like those by Leshob et al., 2018, and Siderska, 2020) suggest that using robotic automation actually makes data security and privacy better. Fung (2014) says that using robots for tasks helps reduce the chances of people getting unauthorized access to data, which makes data security and management better. Better meeting data rules can be done by being clear about processes, keeping track of everything, and making fewer mistakes (Fung, 2014). Moffitt et al. (2018) found that using robotic automation can make processes safer because there is less human contact with sensitive systems and activities can be watched more closely. On the other hand, robots that manage data can be risky, especially when it comes to hacking, according to Flechsig et al. (2022). The robots will sign into systems using the company's login information, which means they can see password, if this information isn't kept safe, it could lead to unauthorized access. If robots are set up incorrectly, it can lead to big problems in the systems they connect to. A harmful robot could carry out tasks that could damage the organization (Fernandez & Aman, 2021). Companies that want to use automated tools to manage sensitive client information, may find that customers are hesitant to use the robotic automation software, this is often due to worries about data security (Cooper et al., 2019). These risks are not just about robotic automation; they can apply to any IT system. There are ways to reduce these risks, and new solutions are always being created (Gotthardt et al., 2020).

The Type of Data

The kind of data can be a problem for robotic automation that doesn't use AI because it needs the data to be organized and saved on a computer (Costa et al., 2022). Robotic automation can't handle unstructured data, like scanned documents, which make up about 90% of all data. As a result, companies need to provide robots with the right data to keep employees focused on more important tasks. According to Gotthardt et al. (2020), cognitive automation tools can manage and analyze unstructured data. However, in this study, the limitations of robotic automation mean that tasks involving unstructured data cannot be automated using this technology (Gotthardt et al., 2020; Hegde et al, 2017).

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High Starting Costs

Setting up automation systems usually needs a lot of money at the start for things like machines, technology setup, and training people. The upfront costs can create financial problems for manufacturers, especially small and medium-sized businesses, and this might stop them from adopting new practices even if there are benefits in the long run.

Possible Job Loss and Unemployment

Machines taking over some jobs could result in people losing their work. Automation can create new jobs for skilled workers who know how to run and fix automated systems, but it might lead to job loss for people whose jobs no longer exist. This movement of people can make social and economic differences worse and require new training programs to help the workers who are affected. Asatiani and Penttinen (2016) and Fernandez and Aman (2021) believe that robotic automation affects jobs and workers, which creates challenges. Like with any new technology, some people might feel scared about robotic automation (Lacity & Willcocks, 2016b) and think of robots as rivals for their jobs (Asatiani & Penttinen, 2016), or that robots might make their jobs less important. If it's not clearly explained and dealt with correctly, this could harm employee morale (Asatiani & Penttinen, 2016). Siderska (2021) says that we don't need to worry about robots making people jobless, but they will change jobs and make companies think about what workers do. Plans to use robotic process automation should involve getting employees involved with the technology, as their participation is key to making it successful (Amaka & Nnenna, 2021).

Reliance on Technology and Risk of Cyber Attacks

As factories use more machines and online systems, they are at risk of problems from technology breakdowns or online attacks. Weaknesses in automated systems can be taken advantage of by bad actors to interfere with production, steal ideas or designs, or disrupt supply chains. This shows how important it is to have strong cybersecurity and ways to reduce risks.

Challenges in Integrating Automation with Existing Systems

Combining new technology with old systems or moving from manual work to automated processes can be difficult and needs careful planning and teamwork. Common problems like compatibility issues, difficulties in sharing data, and reluctance from workers to adapt can hinder successful automation projects. It's important to tackle these challenges to make sure that the automation works well and achieves its goals.

Even though there are challenges, studies have shown that robotic automation can be successfully used and that people have given good feedback after it's been implemented (Asatiani & Penttinen, 2016; Willcocks et al., 2017). Amaka and Nnenna (2021) and Siderska (2021) say that robotic automation is mostly seen as a good thing because its benefits are greater than its drawbacks. So, people view this technology more as a chance for improvement rather than something to fear. Whether we see benefits or face challenges depends on how well we implement robotic automation (Costa et al., 2022).

5. CONCLUSION

Robotic automation is becoming popular in companies as a way to meet their increasing needs for managing work tasks. Using robotic automation is a way for manufacturing organizations to work better. It helps by decreasing the amount of human work needed for regular tasks, making the work better, allowing the business to grow more easily, boosting productivity, and cutting costs (Kirchmer 2017; Fernandez & Aman 2018). This paper presents a new way of looking at how robotic automation affects us, especially the benefits and challenges that have been noted in research. There isn't a single way to understand or use robotic automation, but many studies about it have come out recently (like Costa et al., 2022; Gotthardt et al., 2020; Januszewski et al., 2021; Rutschi & Dibbern, 2020). Based on what we've learned about the benefits and limitations of robotic automation, we want to keep working on a plan for using robotic process automation in manufacturing.

Robots play a crucial and changing role in manufacturing in factories. Robots provide many advantages that help improve how much work gets done, make things safer, and make products better. By using robots to do the same tasks over and over, we can get more work done, make fewer mistakes, and work better overall. They ensure accuracy and dependability in manufacturing, leading to better product quality and satisfied customers. Also, robots can do dangerous and tough jobs, keeping workers safe and allowing human workers to focus on more important tasks. Robots make it easier for factories to change how they manufacture things. They can quickly adjust to new production needs and create custom products. Even though there are problems like starting costs and training employees, the advantages of using robots in manufacturing are greater than the limitations. As robot technology gets

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better, we can look forward to more robots being used in factories. This will make things work faster and better. Robots are going to be very important for the future of manufacturing in factories.

Future Research Directions

Robots are essential for the transformations happening in the manufacturing industry. They help make manufacturing more automated, connected, and flexible. The current research and development in this area suggest that we will see more advanced and capable robots in the future. This will lead to new ideas and change how things are made in factories. Possible benefits can apply to many different fields, such as manufacturing, shipping, and healthcare, creating new opportunities for growth and new innovation. However, using robots comes with challenges, there are worries about ethics, security issues, and how it might affect jobs. As we work to bring these systems into our industries, it's important to tackle these challenges together. This way, we can get the most benefits while also reducing possible risks.

The route to a smart and connected industrial future is still developing and improving, and combining these smart systems will surely influence how industries around the world develop for many years. The area of robotic automation in manufacturing is changing quickly and is very active. Future research ideas for using robotic automation can be explained as:

1. *Improving Human-Robot Collaboration*: Look into new methods and tools to make it easier for people and robots to work together in modern industries. This means creating smart systems that can learn from how people act, guess what users want to do, and change their actions automatically to be more effective and safe.
2. *Making AI in Robots Explainable*: Find ways to make it clear and simple to see how robots make their decisions. Look for ways to connect explainable artificial intelligence (XAI) with smart robots, so that people can understand and trust the choices robots make in complicated work settings.
3. *Teaching Robots to Learn*: This means creating smart programs that help robots get better over time by learning from what they do, the feedback they get, and changes in their surroundings.
4. *Making robotic systems safer from cyber threats*: This means improving the online security of smart robots used in modern industries. Look for new ways to keep robot networks, communication methods, and data exchanges safe, making sure the information stays accurate, private, and accessible in smart factories.
5. *Robotic System Strength*: Look into ways to make robots resilient so they can deal with unexpected problems and fix themselves when something goes wrong. Study ways to keep systems working well even when things go wrong.
6. *Self-Healing Robots*: Learn about robots that can check their own problems, repair themselves, and predict when they need maintenance. Look into new sensor technology, smart computer programs, and robot designs that help machines find and solve problems before they cause failures.

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