Research Article / Review Article FUPRE JOURNAL 8(2): 172-192(2024)

FUPRE Journal

of

Scientific and Industrial Research

ISSN: 2579-1184(Print) ISSN: 2578-1129

(Online)

http://fupre.edu.ng/journal

A Technical Survey on The Role of Robotics in Conventional Manufacturing Process: An Element of Industry 4.0

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ARTICLE INFO

Received: 10/10/2023
Accepted: 23/12/2023

Keywords

Conventional Manufacturing, Future Developments, Industry 4.0, Robotics

ABSTRACT

This technical survey aims to explore the role of robotics in conventional manufacturing processes. The objective of this study is to analyse the impact of robotics on various aspects of manufacturing, including productivity, efficiency, quality, and safety while also argumentatively addressing the benefits and challenges associated with the use of robotics in manufacturing industries. The key points discussed in this survey include the impact of robotics on productivity, cost reduction, and quality improvement in manufacturing. It is obvious that the integration of robotics in manufacturing has revolutionized the industry by enhancing productivity, efficiency, and quality. The use of robotics has significantly increased productivity by automating repetitive tasks, reducing cycle times, and increasing overall production output. Additionally, the implementation of robotics has led to cost reduction through decreased labour costs, minimized material waste, and improved resource utilization. Furthermore, robotics has contributed to quality improvement by ensuring consistent and precise manufacturing processes, reducing errors, and enhancing product reliability. However, the adoption of robotics in conventional manufacturing processes also presents challenges. These challenges include high initial investment costs, the need for skilled technicians to operate and maintain robotic systems, and potential job displacement. Despite these challenges, the long-term benefits of robotics in manufacturing outweigh the initial costs and workforce adjustments. The analysis demonstrates that robotics improves productivity, efficiency, quality, and safety in manufacturing operations. Therefore, the future of robotics in manufacturing looks promising, with advancements in technology paving the way for further improvements. The findings of this survey contribute to a better understanding of the benefits and challenges associated with the integration of robotics in conventional manufacturing processes.

1. INTRODUCTION

As an element of industry 4.0, robotics is a multidisciplinary field that encompasses the design, development, and application of robots. The Fourth Industrial Revolution (IR) also known as Industry 4.0 is the technological evolution of cyber-physical systems, such as high capacity communications, new modes of human-computer interaction such as haptic interfaces and virtual reality systems, and improvements in the transmission of digital instructions to the physical world including robotics and 3D printing (additive manufacturing); the Internet of Things (IoT); "big data" and cloud computing; artificial intelligence-based systems etc (Zheng et al., 2018; Alcácer et

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al., 2019). The term "robot" was first coined by Czech writer Karel Čapek in his play "R.U.R." (Rossum's Universal Robots) in 1920 (Michael and Moran, 2007). Since then, robotics has evolved significantly, and robots have become an integral part of various industries, including manufacturing, healthcare, agriculture, and space exploration. Robotics can be defined as the branch of technology that deals with the design, construction, operation, and application of robots. A robot is an autonomous or semi-autonomous machine that can perform tasks or actions with varying degrees of complexity. These machines are typically equipped with sensors, actuators, and a control system that allows them to interact with their environment and carry out specific tasks. Key components of robotics include:

i. Design: The design of a robot involves creating a physical structure that enables it to perform its intended tasks. This includes determining the size, shape, and materials used in its construction. The design process also involves selecting the appropriate sensors and actuators that enable the robot to perceive and interact with its surroundings.
ii. Construction: Once the design is finalized, the construction phase begins. This involves assembling the various components of the robot, including the mechanical, electrical, and electronic parts. The construction process requires expertise in engineering and manufacturing techniques to ensure the robot's reliability and functionality.
iii. Operation: The operation of a robot involves controlling its movements and actions. This is achieved through a control system that processes sensory information and generates appropriate commands for the robot's actuators. The control system can be programmed using various algorithms and software, allowing the robot to perform specific tasks autonomously or under human supervision.

The main significance of robotics include:

i. Automation: Robotics plays a crucial role in automating repetitive and dangerous tasks that were previously performed by humans. This improves efficiency, reduces human error, and enhances workplace safety. For example, robots are widely used in manufacturing industries to assemble products, perform quality inspections, and handle hazardous materials.
ii. Precision and Accuracy: Robots are capable of performing tasks with high precision and accuracy, surpassing human capabilities in many cases. This is particularly beneficial in fields such as surgery, where robots can assist surgeons in performing delicate procedures with greater precision, minimizing the risk to patients.
iii. Exploration and Research: Robotics has revolutionized space exploration and scientific research. Robots, such as rovers and probes, are used to explore distant planets, gather data, and conduct experiments in environments that are inaccessible or hazardous to humans. These robotic missions have provided valuable insights into the universe and expanded our knowledge of outer space.

Robotics is a multidisciplinary field that involves the design, construction, operation, and application of robots. It encompasses various components, including design, construction, and operation, which are essential for the development of functional and efficient robots. Robotics has significant implications in automation, precision, and

accuracy, as well as exploration and research. As technology continues to advance, robotics will continue to play a vital role in shaping various industries and improving the quality of human life.

1.1. Historical Development of Robotics

The field of robotics has witnessed significant advancements over the years, revolutionizing various industries and transforming the way we live and work. By examining the evolution of robotics, we can gain a deeper understanding of its current state and potential future developments. The origins of robotics can be traced back to ancient civilizations, where early inventors and engineers explored the concept of automata. These mechanical devices were designed to mimic human or animal movements, often serving as entertainment or religious artefacts. One notable example is the ancient Greek engineer Hero of Alexandria, who created a series of automated machines in the 1st century AD. The Industrial Revolution in the 18th and 19th centuries marked a significant turning point in the development of robotics (George and George, 2020). The invention of steam power and the rise of factories led to the need for automated systems to increase productivity and efficiency. This era saw the emergence of early automation technologies, such as Jacquard's loom in 1801, which utilized punched cards to control the weaving process (Ayman and Hafez, 2017).

The term "robot" was coined by Czech playwright Karel Čapek in his 1920 play "R.U.R." (Rossum's Universal Robots). However, it was not until the mid-20th century that significant progress was made in the field of robotics. In 1954, George Devol and Joseph Engelberger developed the first programmable robot, the Unimate, which was used for industrial automation in General Motors' factories (Gasparetto and Scalera, 2019). The late 20th century witnessed rapid advancements in robotics technology, driven by advancements in computing power and electronics. The introduction of microprocessors and sensors enabled robots to perform more complex tasks with greater precision. In 1973, the Stanford Cart became the first autonomous vehicle, showcasing the potential of robotics in navigation and mobility (Bogue, 2023).

In recent years, there has been a significant focus on collaborative robots, also known as cobots. These robots are designed to work alongside humans, enhancing productivity and safety in various industries. Additionally, the integration of artificial intelligence (AI) has revolutionized robotics, enabling machines to learn, adapt, and make decisions autonomously. The future of robotics holds immense potential, with applications ranging from healthcare and agriculture to space exploration and disaster response. However, several challenges need to be addressed for further advancements. These include ethical considerations surrounding the use of robots, ensuring safety and security, and addressing the potential impact on employment (Torresen, 2018).

1.2. The Future of Robotics in Manufacturing Industries

The manufacturing industry has witnessed significant advancements in recent years, with the integration of robotics being one of the most notable developments. Robotics has revolutionized manufacturing processes, leading to increased efficiency, productivity, and cost-effectiveness (Kiradoo, 2017; Musarat et al., 2023). This paper aims to explore the future of robotics in manufacturing industries, focusing on the argument that robotics will continue to play a crucial role in shaping the concept of Industry 4.0. By analysing current trends, technological advancements, and the potential benefits of robotics, this paper will provide a comprehensive understanding of the future prospects of robotics in manufacturing. The current trends in robotics indicate a growing

reliance on automation in manufacturing industries. According to a report by the International Federation of Robotics (IFR), the global sales of industrial robots reached a record high of 384,000 units in 2018 (Heer and Bieller, 2021). This trend is expected to continue, with an estimated annual growth rate of 12% in the coming years. The increasing demand for robotics in manufacturing can be attributed to several factors, including the need for improved productivity, quality control, and cost reduction.

Technological advancements have played a pivotal role in the evolution of robotics in manufacturing industries. The development of artificial intelligence (AI) and machine learning algorithms has enabled robots to perform complex tasks with precision and accuracy. For instance, collaborative robots, also known as cobots, are designed to work alongside human workers, enhancing productivity and safety in manufacturing environments. Furthermore, the integration of sensors, vision systems, and advanced control algorithms has enabled robots to adapt to dynamic environments and perform tasks that were previously considered challenging for automation

The adoption of robotics in manufacturing industries offers numerous benefits.

i. Firstly, robots can significantly improve productivity by performing repetitive tasks with high speed and accuracy, leading to increased output and reduced cycle times.
ii. Secondly, robots can enhance product quality by minimizing human errors and ensuring consistent manufacturing processes.
iii. Thirdly, robotics can improve workplace safety by taking over hazardous tasks, reducing the risk of accidents and injuries.
iv. Lastly, the implementation of robotics can lead to cost savings through reduced labour costs, increased efficiency, and optimized resource utilization.

Despite the numerous benefits, the integration of robotics in conventional manufacturing processes also presents challenges that need to be addressed. These include:

i. High Initial Investment: The cost of acquiring and implementing robotic systems can be a significant barrier for small and medium-sized enterprises (SMEs). The initial investment includes not only the cost of the robots but also the necessary infrastructure, training, and maintenance. Governments and industry stakeholders should explore ways to make robotics more accessible to SMEs through subsidies or financial incentives.
ii. Workforce Adaptation: The introduction of robotics in manufacturing processes requires a skilled workforce capable of operating and maintaining these systems. Upskilling and retraining programs should be implemented to ensure that workers can adapt to the changing work environment. Collaboration between educational institutions and industry is crucial to bridge the skills gap and prepare the workforce for the future of manufacturing.
iii. Ethical and Social Implications: The widespread adoption of robotics in manufacturing raises ethical and social concerns. The displacement of human workers by robots may lead to job losses and economic inequality. It is essential for policymakers and industry leaders to address these concerns by implementing measures such as job retraining programs and ensuring a just transition for affected workers.

The future prospects of robotics in manufacturing industries are promising. As technology continues to advance,

robots will become more intelligent, versatile, and adaptable. The integration of AI and machine learning will enable robots to learn from their experiences, make autonomous decisions, and collaborate seamlessly with human workers. This will result in the emergence of highly flexible and efficient manufacturing systems that can quickly adapt to changing market demands. Furthermore, the development of swarm robotics, where multiple robots work together in a coordinated manner, holds great potential for manufacturing industries. Swarm robotics can enable complex tasks to be performed more efficiently, as robots can divide the workload and collaborate to achieve common goals. This approach can lead to further improvements in productivity, quality, and cost-effectiveness. Advancements in robotics engineering include:

i. Artificial Intelligence (AI) Integration: The integration of AI technologies, such as machine learning and computer vision, has revolutionized robotics engineering. AI enables robots to learn from their environment, adapt to changing conditions, and make intelligent decisions, enhancing their autonomy and versatility.
ii. Human-Robot Interaction: The field of robotics engineering has witnessed significant advancements in human-robot interaction. Collaborative robots, or cobots, are designed to work alongside humans, facilitating seamless cooperation and enhancing productivity. This has opened up new possibilities for applications in industries like manufacturing and healthcare.
iii. Sensing and Perception: Robotics engineering has made significant progress in developing sensors and perception systems that enable robots to perceive and understand their surroundings. This includes technologies such as LiDAR, cameras, and tactile sensors, which provide robots with the ability to navigate complex environments and interact with objects.
iv. Societal Impact: The advancements in robotics applications have had a profound impact on society. On the positive side, robots have increased productivity and efficiency in industries such as manufacturing, leading to cost savings and improved quality. In healthcare, robots have been used for surgical procedures, reducing the risk of human error and improving patient outcomes. Additionally, robots have been deployed in hazardous environments, such as nuclear power plants and disaster zones, to protect human lives.

While the advancements in robotics applications offer numerous benefits, they also raise limitations. These include:

i. Ethical Considerations: As robots become more autonomous and capable of making decisions, ethical considerations arise. Questions regarding robot rights, accountability, and the potential impact on employment need to be addressed to ensure responsible development and deployment of robotics technology. Additionally, there are concerns about privacy and data security when robots are integrated into various aspects of our lives.
ii. Safety and Reliability: Ensuring the safety and reliability of robots is a critical challenge in robotics engineering. Robots must be designed to operate safely in various environments, and rigorous testing and validation processes are necessary to minimize the risk of accidents or malfunctions (Dhillon et al., 2002).
iii. Cost and Accessibility: The cost of robotics technology remains a

significant barrier to widespread adoption. Robotics engineering needs to focus on developing cost-effective solutions that are accessible to a broader range of industries and applications.

1.3. Impacts, Challenges, and Concerns of Robotics

The field of robotics has witnessed significant advancements in recent years, revolutionizing various industries and transforming the way we live and work. While robotics offers numerous benefits, it also presents several challenges and concerns that need to be addressed. These include:

i. Economic Impact: Increased productivity and efficiency in industries (Smith, 2020). Creation of new job opportunities in the robotics industry. Potential for cost reduction in manufacturing processes (Brynjolfsson & McAfee, 2014).
ii. Social Impact: Improved quality of life through robotic assistance in healthcare and elderly care. Enhanced safety in hazardous environments by replacing humans with robots. Increased accessibility and inclusivity for individuals with disabilities (Johnson, 2020).
iii. Ethical Challenges: The potential for job displacement and unemployment due to automation. Ethical dilemmas surrounding the use of autonomous robots in warfare. Privacy concerns related to the collection and use of personal data by robots.
iv. Technical Challenges: Ensuring the safety and reliability of autonomous robots. Developing robust algorithms for complex tasks and decision-making. Overcoming limitations in perception and manipulation capabilities of robots (Misaros et al., 2023; Kabira et al., 2023).
v. Security Concerns: Vulnerability of robots to cyber-attacks and hacking. Potential misuse of robots for criminal activities. Threats to privacy and data security in the context of smart homes and personal robots.
vi. Social Concerns: Impact on human-human interactions and social relationships. Unequal access to robotic technologies, exacerbating existing social inequalities. Psychological implications of human-like robots on human emotions and empathy

1.4. Robotics Applicable to Manufacturing Industries

The manufacturing industry has witnessed significant advancements in automation, with robotics playing a crucial role in enhancing productivity, efficiency, and safety. By understanding these different types, manufacturers can make informed decisions regarding the implementation of robotics in their operations. The forms of robotics applicable to manufacturing industries include:

i. Industrial Robots: Industrial robots are the most common type of robotics used in manufacturing industries. These robots are designed to perform repetitive tasks with high precision and speed, such as assembly, welding, painting, and material handling (Kumar et al., 2019a). They are typically equipped with multiple axes of motion, allowing them to navigate complex workspaces and perform intricate operations. Industrial robots offer increased productivity, improved product quality, and reduced labor costs (Kumar et al., 2019b). However, they require careful programming and may not be suitable for tasks that require human-like dexterity or decision-making capabilities.

ii. Collaborative Robots: Collaborative robots, also known as cobots, are designed to work alongside humans, sharing the same workspace without the need for safety barriers. These robots are equipped with advanced sensors and algorithms that enable them to detect and respond to human presence, ensuring safe and efficient collaboration. Cobots are particularly useful in tasks that require human-robot interaction, such as pick-and-place operations, quality inspection, and packaging (Liu et al., 2020). They offer flexibility, adaptability, and improved ergonomics, allowing manufacturers to optimize their production processes while ensuring worker safety. However, cobots may have limited payload capacities and may not be suitable for heavy-duty applications.

iii. Mobile Robots: Mobile robots are autonomous robots that can navigate and operate in dynamic environments without fixed infrastructure. These robots are equipped with sensors, cameras, and mapping algorithms, enabling them to perceive their surroundings and plan optimal paths. Mobile robots are commonly used for material transportation, inventory management, and warehouse operations (Kumar et al., 2019b). They offer increased flexibility, scalability, and efficiency, as they can adapt to changing layouts and perform tasks in different locations. However, mobile robots may have limited payload capacities and may require additional infrastructure, such as charging stations or navigation aids.

iv. Articulated Robots: Articulated robots are characterized by their multiple rotary joints, resembling a human arm. These robots offer high dexterity and precision, making them suitable for tasks that require complex movements, such as painting, polishing, and assembly of intricate components. Articulated robots can reach into confined spaces and perform operations with high accuracy (Liu et al., 2020). However, they may have limited payload capacities and require careful programming to avoid collisions or singularities.

Figure 1 reflects on the several key robotics aspects for actualizing Industry 4.0 philosophy in practical scenarios. Autonomous robots, cobots, interactive autonomous smart robs, humanoids, mobile robots, cloud robots, pick and place robots, and robotic swarms comprise the most influential robotic technology that impacts advancement in industry 4.0. (Shayganmehr et al., 2021; Mubarik et al., 2021). The manufacturing industry can benefit greatly from the implementation of robotics. Industrial robots provide high productivity and precision, while collaborative robots ensure safe human-robot interaction. Mobile robots offer flexibility and adaptability, while articulated robots excel in tasks requiring complex movements. By understanding the different types of robotics applicable to manufacturing industries, manufacturers can make informed decisions to optimize their production processes and achieve higher efficiency and quality.

1.5.The Trends of Robotics in Manufacturing Industries

The manufacturing industry has witnessed significant advancements in recent years, with the integration of robotics being one of the most prominent trends. Robotics has revolutionized manufacturing processes by enhancing efficiency, productivity, and overall quality. The trends of robotics in manufacturing industries are enumerated as follow:

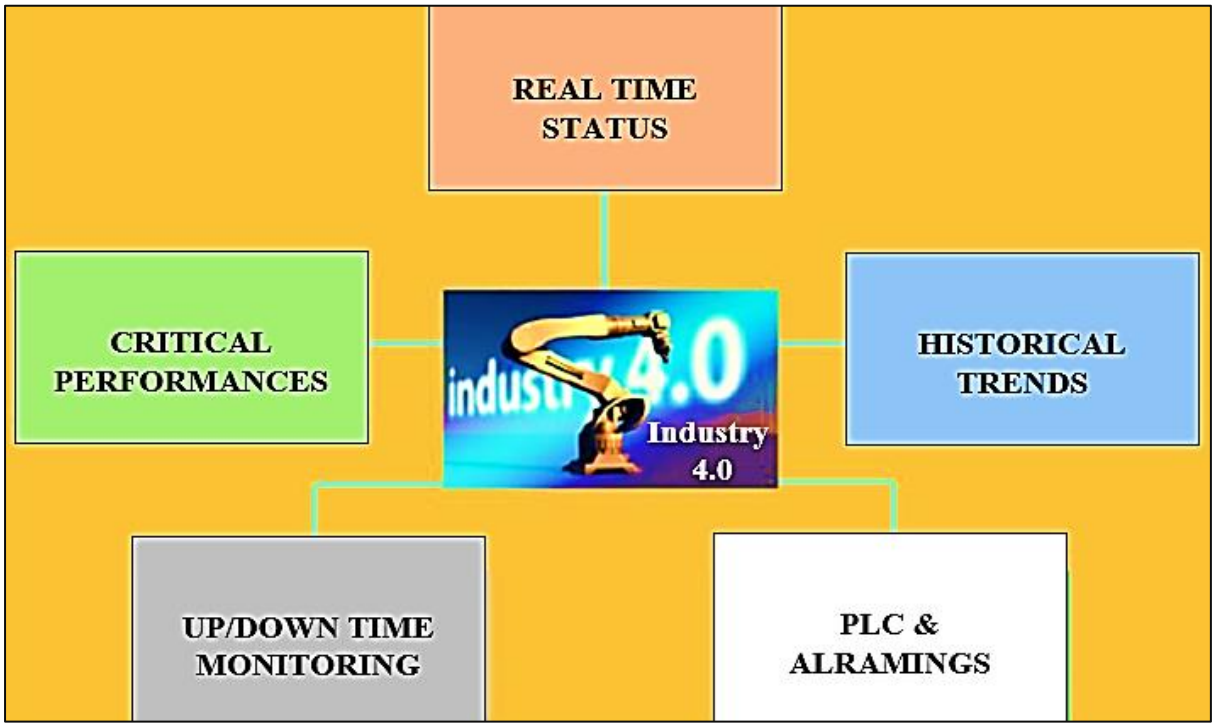

Figure 1: Several key robotics facets for industry 4.0.

i. Automation and Robotics: Automation has long been a crucial aspect of manufacturing, but the integration of robotics has taken it to new heights. Robotics systems are now capable of performing complex tasks with precision and speed, reducing the need for human intervention. This trend has led to increased productivity and improved product quality, as robots can consistently perform tasks without fatigue or errors.

ii. Collaborative Robots: Collaborative robots, also known as cobots, are another significant trend in manufacturing industries. Unlike traditional industrial robots, cobots are designed to work alongside humans, sharing the same workspace. This collaboration allows for increased flexibility and efficiency in manufacturing processes. Cobots can handle repetitive and physically demanding tasks, while humans can focus on more complex and creative aspects of production. (Johnson and Brown, 2019).

iii. Artificial Intelligence and Machine Learning: The integration of artificial intelligence (AI) and machine learning (ML) technologies has further enhanced the capabilities of robotics in manufacturing industries. AI-powered robots can analyze vast amounts of data in real-time, enabling them to make informed decisions and adapt to changing circumstances. ML algorithms

allow robots to learn from their experiences and continuously improve their performance. This trend has led to increased efficiency, reduced downtime, and improved predictive maintenance in manufacturing processes. (Hussain and Pangilinan, 2023).

iv. Internet of Things (IoT) and Connectivity: The IoT has revolutionized various industries, and manufacturing is no exception. The integration of robotics with IoT technologies enables seamless connectivity and communication between different machines and systems. This connectivity allows for real-time monitoring, remote control, and data exchange, leading to improved coordination and efficiency in manufacturing processes. For example, robots can receive instructions and updates from a central control system, ensuring synchronized operations across the production line (Lee and Kim, 2017).

v. Smart Factory Based on PLC Manufacturing Line: The design concept of a smart factory for a manufacturing line using an automatic PLC control system is shown in Figure 2. There are many integrated systems in the main module, and the smart factory is very complex. This includes a combination of connected systems, automation, IoT and cloud computing. It is the primary module of the smart factory, which can be differentiated from the following parts (Hsu et al., 2022).

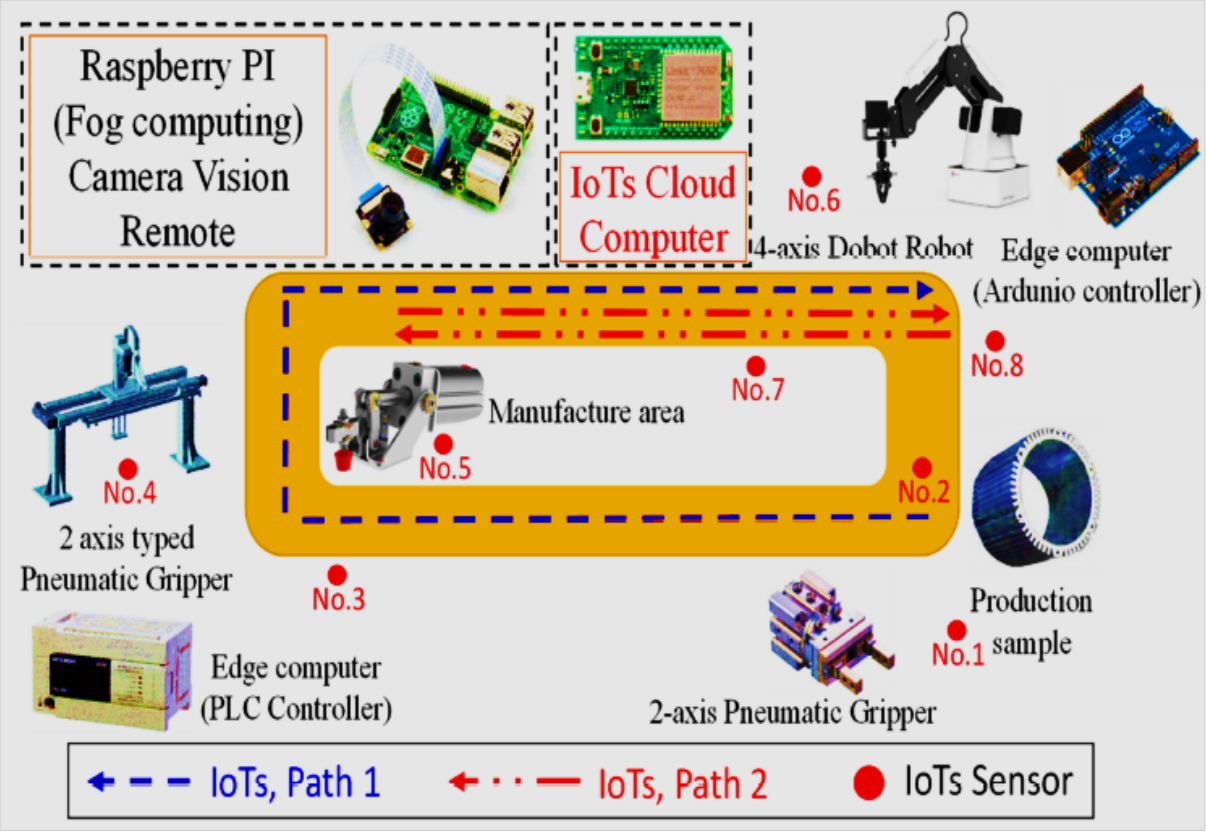

Figure 2: Architecture of an automated manufacturing line

1.6. Robotics in Product Manufacturing: Revolutionizing the Industry

The trends discussed above have numerous benefits for manufacturing industries. Firstly, robotics improves productivity by reducing cycle times and increasing throughput. Robots can work continuously without breaks, leading to higher production rates. Secondly, robotics enhances product quality by minimizing errors and variations in manufacturing processes. Robots can perform tasks with high precision, resulting in consistent and reliable output. Thirdly, robotics improves workplace safety by handling hazardous and physically demanding tasks, reducing the risk of accidents and injuries to human workers.

i. Increased Efficiency and Productivity: Robotic systems have the potential to significantly increase efficiency and productivity in product manufacturing. With their ability to perform repetitive tasks with precision and speed, robots can streamline production processes, reducing human error and increasing output. According to a study by the International Federation of Robotics (IFR), the use of industrial robots can increase productivity by up to 30% in certain manufacturing sectors. This improvement in efficiency allows manufacturers to meet growing demands while maintaining high-quality standards.

ii. Enhanced Precision and Quality: Robots are designed to perform tasks with unparalleled precision, ensuring consistent quality in product manufacturing. Unlike human workers, robots do not experience fatigue or distractions, resulting in fewer errors and defects. This level of precision is particularly crucial in industries where accuracy is paramount, such as electronics and automotive manufacturing. By minimizing variations and defects, robotics contribute to improved product quality and customer satisfaction.

iii. Workplace Safety and Ergonomics: The integration of robotics in manufacturing processes has significantly improved workplace safety. Robots are capable of handling hazardous materials, performing repetitive tasks that may cause strain or injury to human workers. By automating these tasks, manufacturers can reduce the risk of workplace accidents and occupational hazards. Additionally, robots can be programmed to work in environments that are unsuitable or dangerous for humans, further enhancing workplace safety.

iv. Job Creation and Skill Enhancement: Contrary to popular belief, the implementation of robotics in product manufacturing does not necessarily lead to job losses. While some routine tasks may be automated, the introduction of robotics creates new job opportunities in areas such as robot programming, maintenance, and supervision. Moreover, the integration of robotics allows human workers to focus on more complex and creative tasks, fostering skill enhancement and professional growth.

v. Flexibility and Adaptability: One of the key advantages of robotics in conventional manufacturing processes is their ability to adapt to changing production requirements. Robots can be programmed to perform multiple tasks, allowing manufacturers to quickly switch between different products or production lines. This flexibility enables manufacturers to respond to market demands more efficiently and reduces the need for costly retooling or reconfiguration.

vi. Concerns and Mitigation Strategies: Despite the numerous advantages, concerns regarding job displacement and the potential devaluation of human labour persist. To address these concerns, it is crucial to implement appropriate mitigation strategies. These strategies may include retraining programs for workers whose tasks have been automated, ensuring their smooth transition into new roles within the manufacturing process. Additionally, fostering collaboration between humans and robots, where robots assist and augment human capabilities, can lead to a more harmonious and productive work environment.

The integration of robotics in product manufacturing has transformed the industry, offering increased efficiency, precision, and workplace safety. The advantages of robotics in manufacturing far outweigh the concerns surrounding job displacement, as it creates new job opportunities and enhances human skills. By embracing this technology and implementing appropriate mitigation strategies, manufacturers can unlock the full potential of robotics, revolutionizing the industry and driving it towards a more productive and sustainable future. As shown in Figure 3, numerous industry 4.0 aspects for robotics applications include agile assembly and manufacturing which comprises cost effectiveness, utmost quality and anthropomorphic capacity as well as training and learning processes which consist of virtual platforms, quick and nutshell as well as faster and durable processing. Furthermore, the industry 4.0 aspects for robotics applications also include energy maintenance which composes downtime reduction, high efficiency alongside with safety and reliability as well as surgery and related applications which comprises quality checks, error free and effectiveness (Moeuf et al., 2018; Haleem and Javaid, 2020).

1.7.Effects of Robotics on Employment of Manpower in Manufacturing Industries

The rapid advancement of robotics technology has revolutionized the manufacturing industry, leading to significant changes in the employment landscape. It will argue that while robotics has undoubtedly led to job displacement, it has also created new employment opportunities and improved productivity in the sector. Effects of robotics on employment of manpower in manufacturing industries.

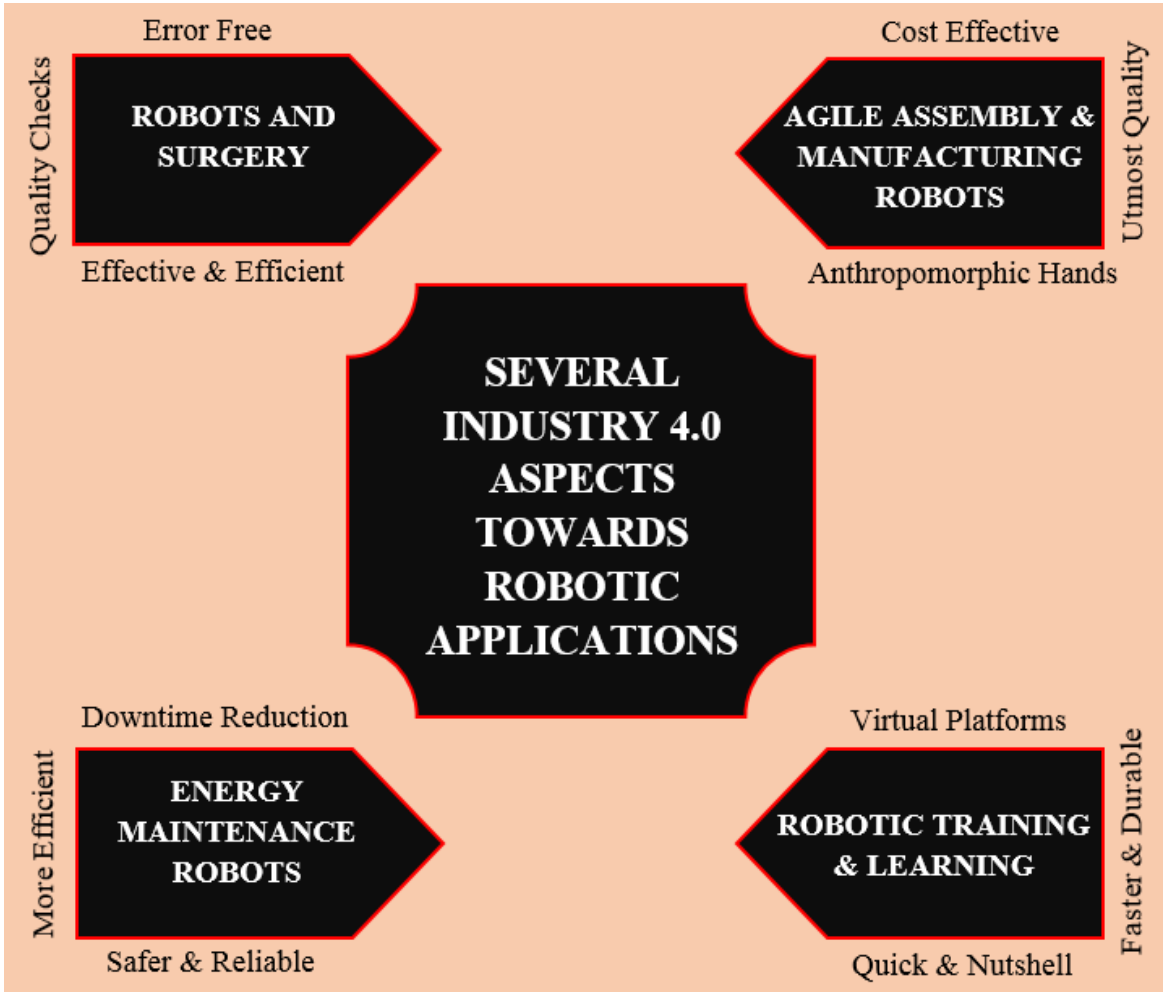

Figure 3: Numerous industry 4.0 perspectives for robotics applications

i. Job Displacement: One of the primary concerns associated with the integration of robotics in manufacturing industries is the potential loss of jobs for human workers. As robots become more sophisticated and capable of performing complex tasks, they can replace human workers in various roles. According to a study by the International Federation of Robotics (IFR), the number of industrial robots deployed worldwide increased by 85% between 2010 and 2016 (IFR, 2017). This trend suggests that many traditional manufacturing jobs are at risk of being automated, leading to unemployment for a significant portion of the workforce.

ii. Improved Productivity: Despite the concerns surrounding job displacement, the integration of robotics in manufacturing industries has also led to improved productivity. Robots can perform repetitive tasks with greater precision, speed, and consistency compared to human workers. This increased efficiency translates into higher production rates and

improved product quality. A study conducted by the Boston Consulting Group (BCG) found that companies that invest in robotics technology experience a 10% increase in productivity on average (BCG, 2015). This boost in productivity allows manufacturers to meet growing demands and remain competitive in the global market.

iii. Creation of New Jobs: Contrary to popular belief, the introduction of robotics in manufacturing industries has also created new job opportunities. While some jobs may be lost due to automation, new roles emerge to support the implementation and maintenance of robotic systems (Atkinson, 2019; Parschau and Hauge, 2020). These include robot programmers, technicians, and engineers who are responsible for designing, programming, and troubleshooting robotic systems. Additionally, the increased productivity resulting from robotics can lead to the expansion of manufacturing operations, creating more jobs in areas such as research and development, marketing, and customer service.

iv. Skill Upgradation: The integration of robotics in manufacturing industries necessitates a shift in the skill set required by the workforce. As routine tasks become automated, there is a growing demand for workers with advanced technical skills to operate and maintain robotic systems. This shift encourages workers to acquire new skills and adapt to the changing work environment. The World Economic Forum (WEF) predicts that by 2025, over half of all employees will require significant reskilling and upskilling (WEF, 2020). Therefore, the introduction of robotics can serve as a catalyst for skill upgradation, enabling workers to remain relevant in the job market.

1.8. The Role of Robotics Engineering in Manufacturing Industries

Robotics engineering has emerged as a pivotal field in the manufacturing industry, revolutionizing the way products are designed, produced, and delivered. By examining the advancements in automation, efficiency, and safety, it becomes evident that robotics engineering is a crucial component in the future of manufacturing.

i. Automation and Efficiency: One of the key benefits of robotics engineering in manufacturing industries is the ability to automate various processes. Robots can perform repetitive tasks with precision and consistency, reducing human error and increasing overall efficiency (Smith, 2018a). This automation allows manufacturers to streamline production lines, resulting in higher productivity and reduced costs. For instance, in the automotive industry, robots are extensively used for welding, painting, and assembly, leading to faster production cycles and improved quality control (Jones, 2019a).

ii. Improved Safety: Another significant advantage of robotics engineering in manufacturing

industries is the enhancement of workplace safety. By replacing humans in hazardous or physically demanding tasks, robots minimize the risk of accidents and injuries (Brown, 2017a). For example, in the chemical industry, robots are employed to handle toxic substances, reducing the exposure of workers to harmful environments. This not only protects employees but also ensures compliance with stringent safety regulations (Smith, 2018b).

iii. Enhanced Precision and Quality: Robotics engineering has also contributed to improved precision and quality in manufacturing processes. Robots can perform intricate tasks with high accuracy, resulting in consistent product quality (Jones, 2019b). This is particularly crucial in industries such as electronics and pharmaceuticals, where precision is paramount. By minimizing human error, robotics engineering ensures that products meet strict specifications, reducing waste and enhancing customer satisfaction (Brown, 2017b).

iv. Job Displacement Concerns: While the benefits of robotics engineering in manufacturing industries are undeniable, concerns regarding job displacement have been raised. Critics argue that the increased use of robots may lead to unemployment and economic inequality (Smith, 2018c). However, it is important to note that robotics engineering also creates new job opportunities. As robots become more prevalent, the demand for skilled technicians, programmers, and maintenance personnel increases (Jones, 2019b). Moreover, the improved efficiency and productivity resulting from robotics engineering can lead to overall industry growth, generating new employment prospects.

Industries utilise robots for a number of manufacturing processes which further improve the effectiveness of the process being implemented to actualize industry 4.0 perspectives. Figure 4 considers several robotic elements which are applied while implementing industry 4.0 sequence at different levels. Some of these robotic elements are material handling which includes Collaborating, Dispensing as well as welding techniques which includes TIG, Plasma, Arc, Spot, Orbital, MIG, MAG etc. Furthermore, the robotic elements for industry 4.0 sequence include miscellaneous applications which comprises Assembly, Coating, Painting, Refuelling, Routing etc. alongside with pick and place type which consist of Visioning, Picking, Palletizing, Pressing etc. (Hizam-Hanafiah and Soomro, 2021; Javed et al., 2021).

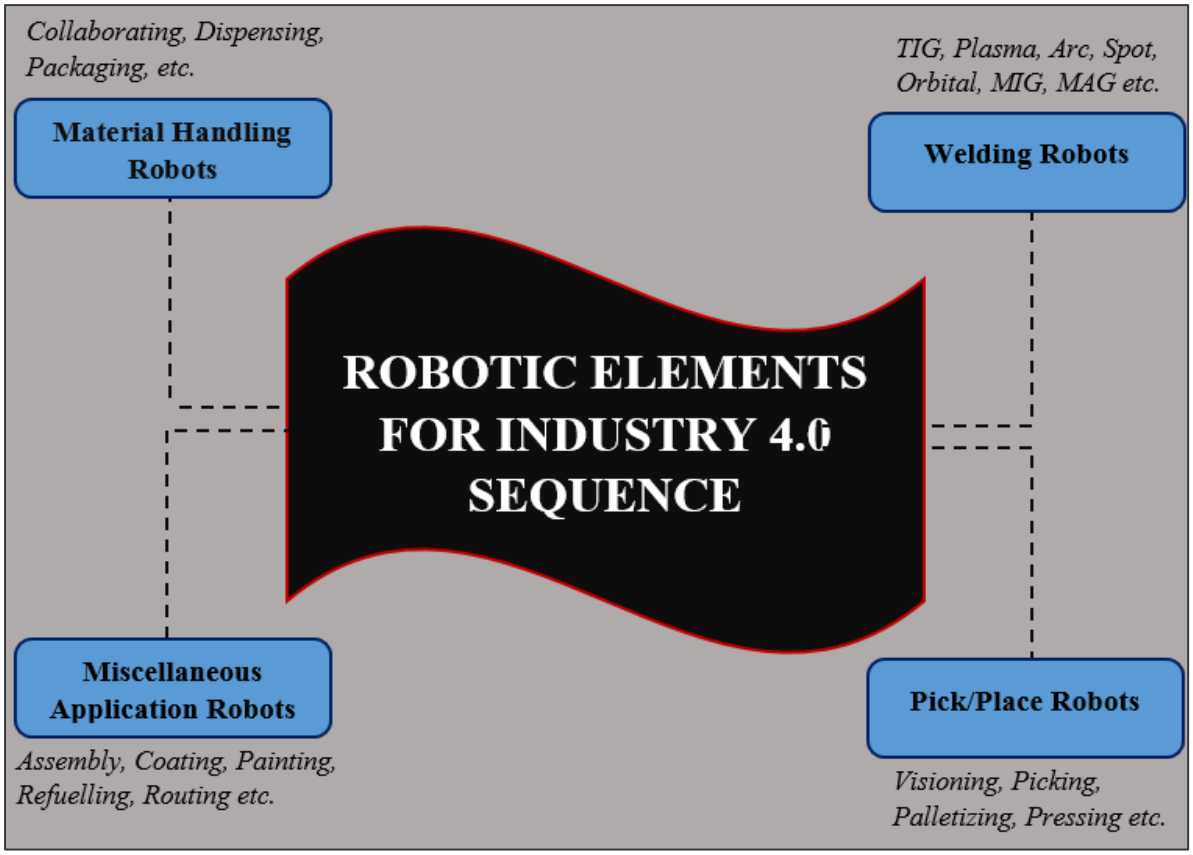

Figure 4: Robotic elements for industry 4.0 sequence

1.9. Transformative Applications of Robotics in Manufacturing Industries

The integration of robotics in manufacturing industries has revolutionized the way products are designed, produced, and delivered. By examining the key benefits and challenges associated with the use of robotics, the advantages of incorporating robotics in manufacturing processes can be demonstrated. The transformative applications of robotics in manufacturing industries include:

i. Increased Productivity: One of the primary advantages of robotics in manufacturing industries is the significant boost in productivity. Robots are capable of performing repetitive tasks with precision and speed, resulting in increased output and reduced production time (Barosz et al., 2020). Unlike human workers, robots do not require breaks, rest, or sleep, allowing for continuous operation and enhanced production rates. This increased productivity ultimately leads to improved profitability for manufacturing companies.

ii. Enhanced Efficiency: In addition to increased productivity, robotics also offers enhanced efficiency in manufacturing processes. Robots can perform complex tasks with minimal errors, ensuring consistent quality and reducing the need for rework or product recalls (Kumar et al., 2019a). Moreover, robots can work in hazardous environments that may pose risks to human

workers, such as extreme temperatures, toxic chemicals, or confined spaces. By automating these dangerous tasks, robotics not only improves efficiency but also safeguards the well-being of workers.

iii. Cost Reduction: The implementation of robotics in manufacturing industries can lead to significant cost reductions. While the initial investment in robotics technology may be substantial, the long-term benefits outweigh the costs. Robots can operate continuously, eliminating the need for overtime pay, employee benefits, and other associated expenses (Brynjolfsson and McAfee, 2014). Additionally, robots can optimize material usage, minimize waste, and reduce energy consumption, resulting in substantial savings for manufacturing companies.

iv. Challenges and Mitigation: Despite the numerous advantages, the integration of robotics in manufacturing industries also presents certain challenges. One major concern is the potential displacement of human workers. As robots take over repetitive and mundane tasks, there is a risk of job loss for some workers (Arntz et al., 2016). However, this challenge can be mitigated by upskilling and reskilling the workforce to adapt to the changing job requirements. By providing training programs and promoting lifelong learning, manufacturing companies can ensure a smooth transition and retain skilled workers.

1.10. Robotics and Human Capacity in the Manufacturing Sector

The manufacturing sector has witnessed significant advancements in recent years, with the emergence of robotics as a viable alternative to human labour. By examining various aspects such as efficiency, precision, adaptability, and cost-effectiveness, this paper can shed light on the potential advantages and limitations of both robotics and human capacity in manufacturing.

i. Efficiency: One of the key advantages of robotics in manufacturing is their ability to perform repetitive tasks with high precision and speed. Robots can work continuously without fatigue, resulting in increased productivity and reduced production time. In contrast, human workers may experience fatigue, leading to decreased efficiency and potential errors. However, it is important to note that humans possess cognitive abilities that allow them to adapt quickly to changing circumstances, which robots may struggle with (Brynjolfsson & McAfee, 2014).

ii. Precision: Robots are known for their exceptional precision, as they can consistently perform tasks with minimal errors. This is particularly crucial in industries that require high accuracy, such as electronics and automotive manufacturing. On the other hand, human workers may possess a higher level of dexterity and flexibility, enabling them to handle complex tasks that require fine motor skills and decision-making abilities.

iii. Adaptability: The ability to adapt to new tasks and environments is a significant advantage of human workers. Humans possess cognitive skills that allow them to quickly learn and adjust to changes in production processes or unexpected situations. In contrast, robots are programmed to perform specific tasks and may require reprogramming or hardware modifications to adapt to new requirements. This lack of adaptability can limit their effectiveness in dynamic manufacturing environments.

iv. Cost-effectiveness: While the initial investment in robotics can be substantial, the long-term cost-effectiveness of automation is often higher than relying solely on human labour. Robots can work around the clock without the need for breaks, vacations, or healthcare benefits, resulting in reduced labour costs. However, it is important to consider that human workers possess problem-solving skills and creativity, which can contribute to innovation and process improvement, potentially offsetting the higher labour costs.

2. CONCLUSION

The future of robotics in manufacturing industries is bright. The current trends, technological advancements, and potential benefits of robotics indicate that automation will continue to play a crucial role in shaping the industry. The integration of AI, machine learning, and swarm robotics will further enhance the capabilities of robots, leading to increased productivity, improved product quality, and cost savings. As manufacturing industries strive to remain competitive in a rapidly evolving global market, the adoption of robotics will be essential for achieving sustainable growth and success. Robotics engineering is a dynamic field that continues to push the boundaries of technological advancements. The integration of AI, advancements in human-robot interaction, and improvements in sensing and perception systems have revolutionized the capabilities of robots. However, ethical considerations, safety concerns, and cost barriers remain challenges that need to be addressed. By addressing these challenges, robotics engineering has the potential to transform industries, improve efficiency, and enhance the quality of human life.

The trends of robotics in manufacturing industries have transformed the way products are produced. Automation, collaborative robots, AI and ML integration, and IoT connectivity have revolutionized manufacturing processes, leading to increased productivity, improved product quality, and enhanced workplace safety. As technology continues to advance, it is expected that robotics will play an even more significant role in shaping the future of manufacturing. Embracing these trends will enable manufacturing industries to stay competitive in an increasingly automated world.

In conclusion, the integration of robotics in manufacturing industries has both positive and negative effects on employment. While job displacement is a concern, robotics has also led to improved productivity, the creation of new jobs, and the need for upskilling. It is crucial for policymakers, industry leaders, and workers to adapt to these changes by

investing in education and training programs that equip individuals with the necessary skills to thrive in the evolving job market. By embracing robotics technology and leveraging its potential, manufacturing industries can achieve sustainable growth and maintain a competitive edge in the global economy.

Robotics engineering has revolutionized manufacturing industries by automating processes, improving efficiency, enhancing safety, and ensuring precision and quality. While concerns about job displacement exist, the overall impact of robotics engineering on employment is positive, creating new opportunities and driving industry growth. As technology continues to advance, the integration of robotics engineering in manufacturing will play an increasingly vital role, shaping the future of production and innovation.

The historical development of robotics has been marked by significant milestones and breakthroughs, transforming various industries and shaping the way we live and work. From ancient automata to modern collaborative robots, the field of robotics has come a long way. With ongoing advancements in technology and the integration of AI, the future of robotics holds great promise. However, it is crucial to address the challenges and ethical considerations associated with this rapidly evolving field. By doing so, we can harness the full potential of robotics for the betterment of society.

The applications of robotics in manufacturing industries have transformed the way products are manufactured, leading to increased productivity, enhanced efficiency, and cost reduction. While challenges such as job displacement exist, the benefits of robotics far outweigh the drawbacks. By embracing robotics and investing in the necessary training and development, manufacturing industries can unlock their full potential and remain competitive in the global market.

The comparison between robotics and human capacity in the manufacturing sector reveals a complex interplay of advantages and limitations. While robots excel in efficiency, precision, and cost-effectiveness, human workers possess adaptability and cognitive skills that are crucial in dynamic manufacturing environments. The ideal approach lies in striking a balance between the two, leveraging the strengths of each to optimize productivity and innovation in the manufacturing sector.

While robotics brings numerous benefits, it is crucial to address the challenges and concerns associated with its rapid development. Ethical considerations, technical advancements, and security measures must be prioritized to ensure the responsible and safe integration of robotics into various domains. By acknowledging and addressing these concerns, we can harness the full potential of robotics while minimizing potential negative impacts on society.

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