Leveraging IoT & AI for Smart Manufacturing through Smart Industrial Automation

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ABSTRACT

Smart manufacturing refers to utilization of advanced technology & data analytics to improve the efficacy and productivity of manufacturing processes. This includes the use of interconnected machines and tools, big data processing, AI, and advanced robotics technology. The goal is to optimize energy and workforce requirements and ultimately improve the overall performance of the manufacturing process. In recent years, amalgamation of disruptive technologies like Industrial Internet, CPS, cybersecurity, data analytics, adaptive robotics and AI, and additive manufacturing has created significant challenges for manufacturing companies and service systems. These challenges arise from the required coordination and connectivity of these technologies. The paper highlights the significance of establishing a connection between different devices and also between humans and machines within a factory environment. This connectivity aids in gathering and analyzing data that can be used to develop innovative solutions for complex problems. Ultimately, it leads to improved quality, reduced costs, and plumated competitiveness in the manufacturing industry. Looking to the future, the direction of smart manufacturing is likely to continue towards greater integration of AI, robotics, and the Internet of Things. The focus will be on developing more advanced and adaptable systems that can respond to changing market demands and improve overall efficiency and productivity. There will also be an increasing emphasis on sustainability and environmental responsibility, with smart manufacturing systems designed to minimize waste and reduce energy consumption. Cybersecurity will remain a critical concern, with companies investing in measures to protect against potential cyber-attacks and ensure the safety and security of sensitive data.

Keywords: AI, CPS, Adaptive Robotics, Cybersecurity, Big Data Analytics.

INTRODUCTION

The significance of industries in promoting economic growth and development cannot be overstated, as they are responsible for job creation, production of goods and services, revenue generation, and overall progress of the country. When industries operate efficiently and productively, they can create a ripple effect that benefits the entire economy. The technical revolution is characterized by the integration of physical systems and virtual systems, leading to an increase in automation, data exchange & advanced technologies like IoT, AI, and robotics [1]. With the implementation of technical revolution technologies, manufacturing industries can improve their productivity by streamlining their processes, reducing manual labour, and minimizing errors. Smart technologies like IoT sensors and machine learning algorithms can help manufacturers identify inefficiencies and optimize production processes. It lead to a reduction in waste, a decrease in downtime, and an increase in overall equipment effectiveness. In addition, Industry 4.0 technologies can help manufacturers create more personalized and customized products, as well as provide better visibility and control over supply chain processes. It can increase customer satisfaction and improved competitiveness in the market. The competition in manufacturing industries has driven the evolution towards smart manufacturing, where digitization and cyber-physical control are used to improve production processes, reduce costs, and meet the demands of the end consumer. Smart manufacturing includes the amalgamation of IoT, AI, and ML to create a connected and intelligent manufacturing environment [2].

By implementing smart manufacturing technologies, manufacturers can improve their responsiveness to changes in the market, reduce production costs, and increase the reliability of their products. For example manufacturers can optimize their operations and minimize waste by utilizing real-time data on production processes obtained through the use of IoT sensors. ML algorithms can examine this data to find trends and anticipate future problems before they arise, enhancing the manufacturing process's overall effectiveness and efficiency. Smart manufacturing technologies can improve communication and collaboration across different departments within a manufacturing plant, as well as between business outlets and suppliers [3]. This can lead to better coordination and faster decision-making, ultimately improving the overall competitiveness and success of the business. The adoption of smart manufacturing technologies is essential for manufacturers to remain competitive in today's fast-paced and rapidly changing market [4].

With the help of the internet, manufacturers can also receive real-time feedback and custom instructions from their customers, allowing for more personalized and tailored goods to be produced. It has the gust to revolutionize the manufacturing industry and streamline the production process [5].

Many countries around the world have recognized the importance of CPS and intelligent manufacturing for the future of their economies and have introduced policies and initiatives to support their development. For example, the United States has launched the Advanced Manufacturing Partnership, which aims to promote the development of advanced manufacturing technologies and create jobs in the industry. Germany has also introduced its Other countries such as China, Japan, and South Korea have also introduced similar policies to support the development of digital manufacturing and CPS [6].

German authorities introduced Industry 4.0. Industry 4.0's primary goal is to create intelligent, highly automated, adaptable, and efficient factories. These factories use interconnected machines and systems that can communicate with each other and with humans, enabling on- time monitoring and control of manufacturing process [7]. This leads to faster production times, higher product quality, and reduced costs. Industry 4.0, which has been adopted by many other nations worldwide, is considered as a vital engine of innovation and competitiveness for the German industrial sector. The integration and application of these technologies enable real- time data exchange, seamless communication, and efficient production processes, ultimately leading to improved product quality, reduced costs, and increased productivity in a highly competitive global market. The objective of Industry 4.0 is to establish a manufacturing ecosystem that is interconnected and unified, allowing for real-time data exchange, seamless communication, and enhanced production processes.

Employing these advanced technologies can help businesses upgrade their product quality, decrease expenses, and boost productivity in a fiercely competitive global market. China has announced several initiatives to enhance its manufacturing industry, including the "Made in China 2025" plan and the "Internet Plus" program [8]. By 9individual production procedures, encouraging innovation, and expanding the use of cutting-edge technologies like robotics, artificial intelligence, and the internet of things, the "Made in China 2025" plan seeks to revolutionise China's manufacturing sector. The plan covers ten main areas of focus, including advanced technology, innovative materials, and smart manufacturing. The "Internet Plus" program, on the other hand, aims to integrate the internet with traditional industries to create a new model of economic growth. These initiatives have had a significant impact on China's manufacturing industry, making it more competitive and innovative. As a result, China's manufacturing industry has seen significant growth and is now one of the world's largest and most advanced manufacturing sectors [9].

Some examples of industrial development strategies by various countries:

1. Germany: "Industries 4.0" strategy, which focuses on the digitalization and automation of industrial production processes.
2. China: The "Made in China 2025" initiative seeks to turn China into a centre of high-tech manufacturing.
3. Japan: "Society 5.0" strategy, which envisions a society where technology is used to solve social challenges.
4. United States: "Manufacturing USA" initiative, which supports industry-driven collaboration and innovation in advanced manufacturing.
5. India: The "Make in India" initiative attempts to encourage indigenous manufacturing and draw in foreign investment.
6. South Korea: The goal of the "Manufacturing Industry Innovation 3.0" plan is to change the manufacturing industry by fusing sophisticated materials with information and communications technology (ICT).
7. Singapore: "Industry Transformation Map" initiative, which focuses on developing high-value industries such as precision engineering, electronics, and chemicals.
8. United Arab Emirates (UAE): "Industrial Strategy 2030" plan, which aims to promote industrial diversification, innovation, and sustainability.
9. France: "Industry of the Future" initiative, which aims to modernize the manufacturing sector.
10. Canada: "Innovation and Skills Plan" strategy, which aims to support innovation, growth, and competitiveness in key sectors such as advanced manufacturing, clean technology, and digital industries.
11. Each country's industrial development strategy reflects its unique economic, political, and social context, as well as its vision for the future of its manufacturing sector.

Table 1: Country & Their Strategies towards Industry 4.0 & Smart Manufacturing

Sr. No.	Country Names	Strategy Names
1.	Germany	Industries 4.0
2.	India	Make in India
3.	UAE	Industrial Strategy 2030
4.	USA	Manufacturing USA
5.	China	Made in China 2025
6.	South Korea	Manufacturing Industry Innovation 3.0
7.	Singapore	Industry Transformation Map
8.	Japan	Society 5.0
9.	France	Industry of the Future
10.	Canada	Innovation and Skills Plan

This research provides a succinct summary of the importance and scope of smart manufacturing systems, as well as some potential directions they may go in the future. The study highlights the importance of smart manufacturing systems in improving product quality, reducing downtime, and increasing cost savings. Finally, the study discusses the potential future directions of intelligent manufacturing, including amalgamation of AI and ML, cybersecurity, sustainability, and human-machine collaboration. The study's objective is to track the most recent industrial applications and their developments across numerous industries. Additionally, the study investigates the utilization of CPS and collaborated devices in intelligent manufacturing & the effects they have [10].

This paper starts with an introductory section that highlights the importance of smart manufacturing systems in different application areas. The subsequent segment covers the evolution of manufacturing and control systems throughout history and explores the various elements that play a role in smart manufacturing systems. Another segment of the paper provides an in-depth analysis of the scope of technologies associated with smart manufacturing and automation systems. Next segment of the paper focuses on the standardization efforts related to smart manufacturing technology. This subdivision may discuss the importance of standardization for ensuring interoperability and compatibility between different systems and technologies in smart manufacturing. Another segment likely covers the challenges that companies may face when implementing smart manufacturing systems. These challenges could include issues related to cybersecurity, the need for significant investments in new technologies and infrastructure, and requirement for upskilling and reskilling of the workforce to adapt to new technologies. Another one, may contain an exploration of future opportunities for smart manufacturing technologies. It may discuss the potential for new technologies such as 5G networks, edge computing, and blockchain to transform smart manufacturing even further. Additionally, the paper likely draws overall conclusions based on the analysis presented in the earlier segments.

Initiation of Industrial Era

In general, the term "industry" refers to the creation of goods and services that take place within a particular economy. It includes various sectors such as manufacturing, construction, agriculture, mining, transportation, and utilities, among others. Depending on how much they participate in the production process, industries can be further divided into primary, secondary, and tertiary sectors [11]. Natural resource acquisition and creation are the core concerns of the primary sector, followed by the production of completed goods and the provision of diverse services by the secondary and third sectors. The industry is a crucial component of any economy, as it contributes to the creation of jobs, income generation, and economic growth. "Industrial revolution" refers to a period of particular economic and technological change that occurred in different stages throughout history. The first industrial revolution, which started towards the end of the 1700s, was marked by the automation of textile manufacturing and the utilization of steam energy. Industrial revolution 2.0 occurred during the late 1800s and early 1900s, and was characterized by the extensive use of electricity, the advancement of mass production techniques, and the expansion of transportation and communication systems [12]. Industrial revolution 3.0, generally referred to digital revolution, commenced in the latter part of the 20th century and is still ongoing. It is distinguished by the extensive incorporation of digital technologies and the emergence of the internet as a dominant force in society. The industrial revolutions led to significant transformations in the methods of manufacturing goods and providing services, and also affected the social and economic systems that facilitated these changes. They also had profound impacts on the global economy, politics, and society as a whole [13].

Industrial Revolution 1.0

This Revolution began in Great Britain in the mid-18th century, around 1765. This period marked a significant shift in the economy as people moved away from traditional, agrarian lifestyles and began to embrace new methods of manufacturing and production. James Watt's development of the steam engine in 1765 served as the primary impetus for the First Industrial Revolution [14]. This new technology allowed machines to be powered by steam, which was a much more efficient and reliable source of power than water or wind. With the steam engine, factories could be built anywhere, not just near a source of water or wind power.

Another key development of the First Industrial Revolution was the mechanization of textile production. Before the revolution, textiles were produced by hand using spinning wheels and looms. However, in the late 1700s and early 1800s, inventors such as Richard Arkwright and Edmund Cartwright developed new machines that could spin and weave cloth much more quickly and efficiently than humans could [15].

The advent of steam engines and technological advancements enabled factories to produce goods in larger quantities, resulting in the expansion of urban areas and the emergence of numerous employment opportunities within the manufacturing and industrial sectors. The First With the creation of new technologies like the steam locomotive and the steamship, the Industrial Revolution had a big impact on transportation as well. Long-distance transportation of both people and products became quicker and easier as a result, which accelerated the development of trade and industry [16]. Overall, the First Industrial Revolution transformed the economy and society in profound ways, laying the foundation for the modern world we live in today.

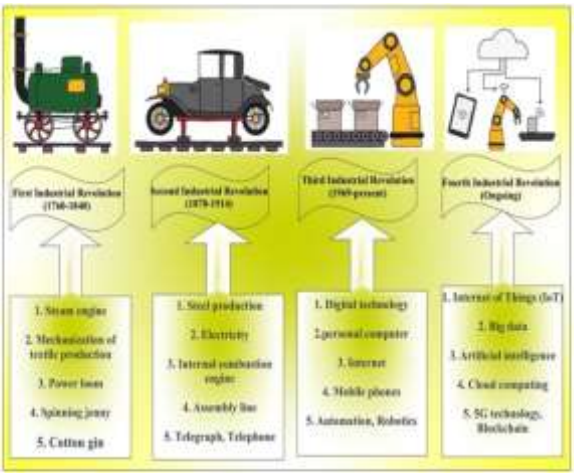

Figure 1 Era of Industrial Revolution

Industrial Revolution 2.0

It took place from the late 1800s to the early 1900s and was marked by substantial technological innovations and economic progress. It involved the implementation of advanced manufacturing methods, the creation of new forms of energy, and the enlargement of communication and transportation systems [17]. The following are some of the major developments that took place during this period:

1. New Manufacturing Techniques: The Second Industrial Revolution saw the introduction of new manufacturing techniques that significantly increased efficiency and productivity. One of the most important developments was the use of assembly line production, which allowed for the mass production of goods at a lower cost. Other innovations included the use of interchangeable parts, precision machinery, and the development of new materials such as steel and aluminium.
2. Development of New Energy Sources: The Second Industrial Revolution saw the widespread adoption of new energy sources such as electricity, oil, and gas. These new sources of energy allowed for the development of new industries such as electric power generation, petroleum refining, and natural gas production.
3. Expansion of Transportation Infrastructure: The Second Industrial Revolution saw the expansion of transportation infrastructure such as railroads, steamships, and automobiles. These developments allowed for the efficient transportation of goods and people over long distances, which facilitated trade and economic growth.
4. Communication Infrastructure: The Second Industrial Revolution also saw the development of new communication infrastructure such as the telegraph and telephone. These innovations allowed for the rapid transmission of information over long distances, which facilitated trade and commerce.

Industrial Revolution 2.0 led to significant increases in productivity, lower costs of goods, and the growth of new industries. The advancements of the industrial revolutions had far-reaching impacts on society and the economy, including the proliferation of urban areas, the establishment of novel industries, and the enlargement of the middle class [18, 19].

Industrial Revolution 3.0

The Digital Revolution or Third Industrial Revolution started in the late 1960s and early 1970s and refers to a period of significant technological progress.

It was marked by the emergence of digital technologies and the widespread usage of computers and the internet [20]. Here are some of the major developments that took place during this period:

1. Development of Digital Technologies: The Third Industrial Revolution was marked by the development of digital technologies such as microprocessors, semiconductors, and integrated circuits. These technologies allowed for the development of smaller, faster, and more powerful computers, which became the backbone of the digital revolution.
2. Widespread Adoption of Computers: The Third Industrial Revolution saw the

widespread adoption of computers in homes, businesses, and government institutions. This led to the automation of many tasks previously done manually, which led to increased efficiency and productivity.

3. Emergence of the Internet: One of the most significant developments of the Third Industrial Revolution was the emergence of the internet. The internet allowed for the rapid transmission of information and facilitated communication between individuals and businesses around the world.
4. Growth of E-commerce: With the rise of the internet, e-commerce emerged as a new way of conducting business. Online shopping became increasingly popular, and businesses began to invest in digital marketing and advertising.
5. Expansion of Telecommunications: The Third Industrial Revolution also saw the expansion of telecommunications infrastructure, which facilitated the transmission of data over long distances. New technologies, like wireless networks and mobile phones, were developed as a result.

The way people work and interact has significantly changed as a result, and new businesses like e-commerce and digital marketing have been made possible. With the emergence of new technologies like artificial intelligence, blockchain, and the Internet of Things, the digital revolution is still evolving today [21].

Industrial Revolution 4.0

The current stage of technological development during which digital, physical, and biological systems are coming together is known as the Fourth Industrial Revolution (4IR). It builds on the rise of technologies like artificial intelligence, robotics, the Internet of Things (IoT), and blockchain is a hallmark of the Third Industrial Revolution [22]. Here are some of the major developments that are taking place during this period:

1. Artificial Intelligence (AI): Machines that are programmed to learn and carry out activities that would typically need human intellect are said to have artificial intelligence (AI), which is the simulation of human intelligence. Many different applications, such as chatbots, image and speech recognition, and self-driving automobiles, use artificial intelligence.

2. Robotics: The design of machines that can carry out tasks that are typically done by humans is the focus of the field of robotics. It involves the design, construction, and operation of these machines. Robotics finds its applications in various fields such as manufacturing, healthcare, and logistics, to name a few.

3. Internet of Things (IoT): The Internet of Things, also known as IoT, is a network of physically connected objects like vehicles, appliances, and other gadgets that can communicate and share data with one another thanks to software, sensors, and internet connectivity. It can be used in a variety of settings, including smart homes, smart cities, and industrial automation.

4. Blockchain: The blockchain is a type of digital record-keeping system that enables secure and transparent transactions without the involvement of intermediaries like banks or other financial institutions. Numerous applications, including voting systems, supply chain management, and cryptocurrencies all make use of blockchain technology.

5. 3D Printing: The method of 3D printing involves adding successive layers of material to computer models to create tangible objects. It is employed in many different fields, including as manufacturing, healthcare, and architecture.

Fourth Industrial Revolution is enabling new forms of collaboration, innovation, and productivity. However, it is also raising important questions about the implications of these technologies on privacy, security, and employment [23,24].

Principles & Operating Ideologies of Industry 4.0

Industry 4.0, in which digital technologies are being incorporated into manufacturing processes. Industry 4.0’s guiding concepts are as follows:

A. Interoperability: This idea 12individual how important it is for people, machines, sensors, and other objects to be able to connect and interact with one another, regardless of who made them or where they came from. Interoperability enables different systems and devices to communicate and exchange data with each other seamlessly, regardless of their manufacturer or origin. This principle is essential for creating a connected ecosystem where machines, devices, sensors, and people can work together efficiently and effectively. Interoperability enables organizations to integrate new technologies into their existing systems and devices, enhancing their capabilities and improving their performance. It also enables organizations to collaborate with other companies and stakeholders, creating new opportunities for innovation and growth [25].

B. Modularity: This principle involves breaking down production processes into smaller, modular components that can be easily modified or replaced.

This makes production processes more flexible and adaptable to changing market conditions. It involves breaking down production processes into smaller, modular components that can be easily modified or replaced.

C. This approach makes production processes more flexible and adaptable to changing market conditions, enabling organizations to respond quickly to new opportunities or challenges. Modularity also facilitates the integration of new technologies and equipment into existing production processes, enabling organizations to improve their performance and efficiency. Additionally, modular production processes can be easily replicated and scaled up or down, providing organizations with greater agility and scalability [26].

D. Real-time capability: This principle involves the use of real-time data to optimize production processes and improve decision-making. Real-time data collection is necessary for this, thus sensors and other monitoring tools must be used. It entails having the capacity to gather and analyse data in real-time in order to 13individual business decisions. With the use of real-time data, businesses can keep an eye on their production processes, see any problems or inefficiencies right away, and then act promptly to fix them. This approach improves the overall efficiency and productivity of production processes, reducing costs and improving quality. Real-time data also enables organizations to make more accurate predictions about future demand and adjust their production processes accordingly, improving their agility and responsiveness [27].

E. Service orientation: This philosophy entails switching from a service-centric to a product- centric mindset, where the emphasis is on offering clients 13ndividualiz solutions rather than just selling things. It entails a change from a service-centric to a product-centric strategy, where the emphasis is on offering clients 13ndividualiz solutions rather than just selling things. This approach enables organizations to create new revenue streams and differentiate themselves in a competitive market. By offering customized services, organizations can meet the specific needs of their customers, improving customer satisfaction and loyalty. Service orientation also enables organizations to create new business models, such as subscription-based services, which provide a more predictable revenue stream [28].

F. Decentralization: Instead than depending on a 13ndividuali decision-making framework, this approach calls for the distribution of decision-making authority throughout the 13ndividualiz. This makes it possible to be more flexible and responsive to shifting market conditions. Decentralisation, a key tenet of Industry 4.0, is giving employees at all 13ndividualized levels the freedom to make decisions and conduct actions based on real-time data. This strategy helps businesses be more agile and competitive by enabling them to react swiftly to shifting market conditions and client needs. Employee experimentation with novel concepts and strategies is fostered by 13ndividualized13n, which also fosters innovation and creativity. Decentralisation can also increase job satisfaction and employee engagement since it gives workers a sense of agency and appreciation for what they bring to the table for the company [29].

G. Virtualization: This principle involves creating virtual representations of physical objects and processes, allowing for simulation and optimization of production processes. It involves creating virtual models of physical objects, machines, and processes. Through the use of these virtual models, production processes may be 13ndividua and simulated, allowing businesses to spot possible problems early on and take appropriate action. Additionally, virtualization enables businesses to test new goods and procedures in a virtual setting, doing away with the need for actual prototypes and cutting expenses. Additionally, virtualization can improve collaboration and communication between different teams and departments, as everyone can access and work with the same virtual models [30].

H. Automation: This principle encompasses the application of automation technologies to enhance efficacy, curtail expenses, and boost output. It involves utilizing robotics, artificial intelligence, and machine learning. Robotics, AI, and machine learning are examples of automation technology. By automating repetitive and normal processes, these technologies help organisations to free up staff time for more difficult and creative work. In addition to lowering the risk of errors and faults, automation can enhance the precision and quality of manufacturing operations. Additionally, automation can reduce costs by optimizing energy consumption, minimizing waste, and improving supply chain management. Overall, automation is a key driver of efficiency and competitiveness in the Industry 4.0 era [31].

Operating Ideologies of Industry 4.0

The operating ideologies of Industry 4.0 are based on the principles of digitization, automation, and connectivity. Here are some key operating ideologies of Industry 4.0:

IoT (Internet of Things):

Industry 4.0 is characterized by the extensive use of IoT devices, which are connected to the internet and capable of exchanging data with other devices and systems. A group of actual physical objects, including equipment, structures, and vehicles, that include software, sensors, and internet connectivity is referred to as the "Internet of Things" (IoT) [32]. These objects can communicate with each other and with other systems via the internet, providing prompt and relevant data that can be used to improve operations and efficiency. In the context of Industry 4.0, IoT devices play a crucial role in enabling the automation and optimization of various processes in industries such as manufacturing, logistics, and healthcare. IoT sensors, for instance, can be used in a manufacturing facility to track the movement of materials and goods, check the health of machines and equipment, and measure various environmental variables like temperature and humidity. Once possible problems or inefficiencies have been identified using this data, operators can move to address them before they become serious. For example, if a machine is showing signs of wear and tear, the IoT sensors can alert operators to the issue, allowing them to schedule maintenance before a breakdown occurs [33]. Similarly, in logistics, IoT devices can be used to track the movement of goods and optimize delivery routes, reducing shipping times and costs. And in healthcare, IoT sensors can be used to monitor patient conditions and track the usage of medical devices, ensuring that patients receive the right treatment at the right time. Overall, the extensive use of IoT devices in Industry 4.0 enables companies to collect and analyze vast amounts of data, providing valuable insights that can be used to improve efficiency, reduce costs, and enhance overall performance [34].

Big Data: Industry 4.0 generates massive amounts of data, which can be analysed in real-time to optimize production processes and improve decision-making. Big data refers to large and complex data sets that are difficult to process using traditional data processing techniques. The fourth industrial revolution is known as "Industry 4.0," and it is 14ndividualize by the use of cutting-edge technology like the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML) in production processes. Massive amounts of data are produced by Industry 4.0 from a variety of sources, including sensors, machines, and production systems. Big data analytics technologies can be used to gather, store, and analyse this data in real-time so that smart decisions can be made, production processes can be better understood, and patterns can be found. For example, by analyzing the data generated by sensors in manufacturing equipment, companies can identify potential issues before they occur, optimize production processes by identifying bottlenecks and inefficiencies, and improve product quality by detecting defects early in the process. Real-time analysis of big data can also help companies to adapt quickly to changing market conditions, implement predictive maintenance, and reduce downtime, thereby increasing productivity and profitability.

The use of big data analytics in Industry 4.0 provides manufacturers with the ability to optimize production processes, improve decision-making and gain a competitive edge in the marketplace [35].

Artificial Intelligence and Machine Learning: Industry 4.0 leverages AI and machine learning technologies to automate tasks, optimize processes, and improve overall efficiency. Artificial Intelligence (AI) and Machine Learning (ML) are two advanced technologies that are being leveraged by Industry 4.0 to automate tasks, optimize processes, and improve overall efficiency [35,36].

Robots with artificial intelligence (AI) can do activities that often require human intelligence, such as pattern recognition, natural language understanding, and decision-making. Algorithms in machine learning (ML) are used to learn from data and produce judgements or predictions without being explicitly programmed. A division of AI is ML. In Industry 4.0, basic jobs like data entry and analysis are automated using AI and ML, freeing up human workers to concentrate on more difficult tasks that call for creativity and problem-solving abilities. For example, AI- powered robots can be used to perform repetitive tasks on the factory floor, such as assembling components or packing products, while ML algorithms can be used to predict equipment failures and initiate maintenance before the failure occurs. AI and ML can also be used to optimize processes by analyzing data from various sources, such as sensors and production systems, to identify inefficiencies and suggest improvements [37]. For example, ML algorithms can analyze data from sensors on a production line to identify bottlenecks and suggest changes to the production process to increase efficiency. AI and ML can be used to improve overall efficiency and productivity by analyzing large volumes of data and providing insights that can be used to make better decisions. For example, predictive analytics can be used to forecast demand for products, allowing manufacturers to adjust production schedules to meet demand and avoid overproduction. The use of AI and ML in Industry 4.0 is revolutionizing the manufacturing industry by automating tasks, optimizing processes, and improving overall efficiency. This is leading to increased productivity and profitability, as well as improved product quality and customer satisfaction [37].

Cyber security: Industry 4.0 demands strong cyber security measures in order to defend against cyber threats and guarantee the confidentiality, integrity, and availability of data and systems. The Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML), all of which are internet-connected and susceptible to cyber attacks, are key components of Industry 4.0. Strong cybersecurity measures are needed to defend against cyber threats and guarantee the privacy, integrity, and availability of data and systems. One of the main cybersecurity challenges in Industry 4.0 is the large number of connected devices and systems, which increase the attack surface and make it difficult to manage and secure them all [38]. To address this challenge, companies need to implement a comprehensive cybersecurity strategy that includes the following measures:

a. **Risk Assessment:** Companies need to conduct a risk assessment to identify potential cybersecurity risks and vulnerabilities in their systems and devices.

b. **Cybersecurity Policies:** Companies need to develop and implement cybersecurity policies and procedures that outline how to manage and secure their systems and devices.

c. **Network Segmentation:** Companies need to segment their networks to isolate critical systems and devices from less critical ones, making it more difficult for cyber attackers to move laterally within the network.

d. **Access Controls:** Companies need to implement access controls to restrict access to critical systems and devices to authorized personnel only.

e. **Encryption:** Companies need to encrypt their data to protect it from unauthorized access and ensure its confidentiality.

f. **Incident Response Plan:** Companies need to develop and implement an incident response plan that outlines how to respond to a cybersecurity incident, including how to contain the incident, investigate the cause, and restore normal operations.

g. **Employee Training:** Companies must educate their employees on cybersecurity best 15ndividua, such as identifying and reporting suspicious activity and safeguarding sensitive information. Companies need to implement a comprehensive cybersecurity strategy that includes risk assessment, cybersecurity policies, network segmentation, access controls, encryption, incident response plan, and employee training [38,39].

Decentralized Decision-Making: Industry 4.0 involves distributing decision- making power throughout the organization, allowing for greater agility and responsiveness to changing market conditions. Decentralized decision-making is a key feature of Industry 4.0, which enables companies to respond more quickly and effectively to changes in the market and customer needs. In a decentralized decision- making model, employees at all levels of the organization are empowered to make decisions based on their knowledge and expertise. This approach allows for faster decision-making, as decisions can be made at the point of need, without the need for approval from a centralized authority. Decentralized decision-making also allows for greater flexibility and adaptability, as decisions can be made quickly in response to changing market conditions or customer needs. This is particularly important in the fast-paced and dynamic environment of Industry 4.0 [39,40].

This can result in new ideas and solutions that can drive business growth and success. However, decentralized decision-making can also present challenges, such as the potential for conflicting decisions and the need for clear communication and coordination across the organization. To address these challenges, companies need to establish clear decision-making processes and communication channels to ensure that decisions are aligned with the company's overall strategy and goals. Decentralized decision-making is a key feature of Industry 4.0 that enables companies to respond more quickly and effectively to changes in the market and customer needs. While it presents challenges, companies that embrace decentralized decision-making can achieve greater agility, flexibility, and innovation, leading to business success and growth [40] .

Flexibility and Adaptability: Industry 4.0 emphasizes the need for production processes to be flexible and adaptable to changing market conditions, customer demands, and technological advances. One of the key features of Industry 4.0 is the emphasis on flexibility and adaptability in production processes. This is because the market conditions, customer demands, and technological advancements are changing at a fast pace, and manufacturers need to keep up with these changes to remain competitive.

Flexibility refers to the ability of a manufacturing system to respond quickly and efficiently to changes in the production process. For example, if there is a sudden increase in demand for a particular product, a flexible production system can quickly adjust the production schedule to meet the increased demand. Adaptability refers to the ability of a manufacturing system to integrate new technologies and systems into the production process. For example, if there is a new technology that can improve the efficiency of the production process, an adaptable production system can quickly integrate this technology into its operations to improve its performance. Flexibility and adaptability are critical for manufacturers who want to remain competitive in the market. Industry 4.0 emphasizes the need for manufacturers to embrace these concepts to ensure that their production processes can quickly respond to changes in the market, customer demands, and technological advancements [41,42].

Customer-Centricity: Industry 4.0 is focused on providing customized solutions to customers, rather than just selling products. This requires a deep understanding of customer needs and preferences. Customer-centricity is an important aspect of Industry 4.0. With the increasing availability of data and advanced analytics, manufacturers can gain a deeper understanding of customer needs and preferences. This allows them to develop customized solutions that meet the unique needs of each customer [42]. Customer-centricity involves more than just selling products. Manufacturers must concentrate on fostering long-lasting relationships with consumers by offering them 16ndividualized experiences and solutions. Increased consumer loyalty and repeat business may result from this. To become customer-centric, manufacturers must adopt new technologies and processes that allow them to collect and analyze customer data. They must also be willing to collaborate with customers to co-create solutions that meet their specific needs. Customer-centricity is an essential part of Industry 4.0. By focusing on the needs and preferences of customers, manufacturers can create more personalized and effective solutions that drive growth and profitability [42].

Collaborative Ecosystems: Industry 4.0 involves the creation of collaborative ecosystems, where companies, suppliers, and customers work together to co-create value and drive innovation. Collaborative ecosystems are a key aspect of Industry 4.0. This involves the creation of networks of companies, suppliers, and customers who work together to share knowledge, resources, and expertise to co-create value and drive innovation [43].

Collaborative ecosystems can take many forms, such as partnerships, joint ventures, and open innovation networks. They bring together different perspectives and expertise to solve complex problems and create new solutions. In Industry 4.0, the use of digital technologies and data analytics is making it easier to create collaborative ecosystems. For example, cloud-based platforms and digital marketplaces can connect different companies and stakeholders and facilitate collaboration and knowledge-sharing. By working together, companies can leverage their strengths, pool resources, and create more innovative and effective solutions that drive growth and profitability [44].

Sustainable Production: Industry 4.0 aims to minimize the environmental impact of production processes by optimizing resource utilization, reducing waste, and improving energy efficiency. Sustainable production is a key goal of Industry 4.0. The integration of digital technologies into manufacturing processes provides new opportunities to optimize resource utilization, reduce waste, and improve energy efficiency, all of which contribute to environmental sustainability [45]. For example, the use of sensors and data analytics can help manufacturers optimize the use of energy and resources by providing real-time information about the performance of production processes. This can help identify areas where energy or resource use can be reduced, leading to cost savings and reduced environmental impact. Industry 4.0 also enables the use of circular economy principles, such as the reuse and recycling of materials and products. This can help reduce waste and extend the life cycle of products, resulting in a more sustainable production process. Industry 4.0 has the potential to help manufacturers minimize their environmental impact by optimizing resource utilization, reducing waste, and improving energy efficiency [46,47].

Operating Ideologies Formulation

$$\mathrm{C = w1M + w2P + w3Q + w4T}$$

Subject to the following constraints:

$$M \leq Mmax$$
$$P \leq Pmax$$
$$Q \geq Qmin$$
$$T \leq Tmax$$

We are attempting to reduce the cost (C) of smart manufacturing in this equation by optimising four variables: machines (M), processes (P), quality (Q), and time (T). Each variable's relative importance in the cost function is represented by the weights $w1$, $w2$, $w3$, and $w4$. For example, if we place a higher value on reducing production time than on improving product quality, we would give $w4$ a higher weight than $w3$. The constraints ensure that we keep each variable within certain limits. $Mmax$, for example, represents our machines' maximum capacity, $Pmax$, the maximum number of processes we can implement, $Qmin$, the minimum acceptable level of quality, and $Tmax$, the maximum time allowed for production. We can use various methods to solve this optimisation problem, such as linear programming or nonlinear programming, to find the values of M, P, Q, and T that minimise the cost C while satisfying the constraints. To reduce the value of C, we must employ a technique known as linear programming or the simplex method. Solving a system of linear equations containing the objective function and constraints is required. $C = w1M + w2P + w3Q + w4T$ is the objective function, which is a linear combination of four variables M, P, Q, and T. Each of these variables has a weight or coefficient ($w1, w2, w3, and\ w4$) that determines its importance in the objective function.

The constraints are the conditions that must be met in order for a valid solution to be found. These can include restrictions on the variables' own values as well as restrictions on how they can be combined. After we've defined the objective function and constraints, we can use linear programming or the simplex method to find the optimal values of $M, P, Q,$ and T that minimise the value of C.

Smart Manufacturing Opportunities and Future Directions across the Globe

Smart manufacturing is a rapidly growing field, and opportunities for its adoption can be found across the globe. Some of the main prospects and future directions for smart manufacturing are as follows:

1. North America: The smart manufacturing market in North America is expected to grow significantly due to the high adoption of IoT, cloud computing, and big data analytics. The US government has also launched several initiatives to support smart manufacturing, such as the Advanced Manufacturing Partnership and the National Network for Manufacturing Innovation [48].

2. Europe: The European Union has launched the Industry 4.0 initiative to promote the adoption of smart manufacturing across the region. The European Commission has also set up several funding programs to support smart manufacturing projects, such as the Horizon 2020 program [49].

3. Asia-Pacific: The Asia-Pacific region is expected to be the fastest-growing market for smart manufacturing due to the increasing adoption of Industry 4.0 technologies in countries such as China, Japan, and South Korea. The Chinese government has launched the Made in China 2025 initiative to promote smart manufacturing in the country [49].

4. Middle East and Africa: The smart manufacturing market in the Middle East and Africa is also growing, with several countries investing in Industry 4.0 technologies. For example, the UAE has launched the Dubai Industrial Strategy 2030, which aims to transform the country into a global hub for smart manufacturing.

In terms of future directions, smart manufacturing is expected to continue evolving and expanding. Some of the key trends include the integration of AI and machine learning into smart manufacturing systems, the development of more advanced sensors and IoT devices, and the increasing use of digital twins for simulation and optimization. Overall, the global market for smart manufacturing is expected to continue growing as more and more companies adopt these technologies to improve efficiency, reduce costs, and stay competitive in the global market [50].

CONCLUSION

Modern industrial manufacturing is being revolutionised by smart manufacturing systems, which are also essential to the adoption of superior manufacturing technology. The application of cutting-edge technologies, such as artificial intelligence, cyber-physical systems, big data processing, augmented and virtual reality, IoT, and robotics, to optimise and automate industrial processes is known as smart manufacturing technology. Due to the interdependence and interrelationship of these technologies, proper development and industrial sector integration are essential for their successful application. Compared to conventional production systems, smart manufacturing solutions are intended to be more effective, adaptable, and versatile To enhance manufacturing procedures, decrease waste, and boost productivity, they use cutting-edge technology like the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and machine learning. Smart manufacturing solutions can assist manufacturers in streamlining their production processes, finding any inefficiencies, and making data-driven decisions by utilising real-time data and analytics. This may result in lower expenses, higher quality, and greater profitability. Smart manufacturing systems can also assist manufacturers in better monitoring and maintaining their equipment, which will decrease downtime and increase reliability. This may result in more output and, ultimately, greater profitability. The implementation of superior manufacturing technology is largely dependent on smart manufacturing systems, which are a crucial part of the present industrial age. As technology continues to evolve, we can expect to see even more advanced and powerful smart manufacturing systems in the future.

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