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INDUSTRY 5.0: A STUDY ON SUPPORTING TECHNOLOGY SYSTEMS, APPLICATIONS, AND FUTURE DIRECTIONS

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1. Introduction

Next-generation wireless networks that are intelligent, resilient, and dependable are expected to serve as a technological enabler for meeting the various communication and computation needs of Industry 5.0 services and applications (Ji, 2021), which are built on the foundation of three key concepts: sustainability, resilience, and human-centered industry (Maddikunta, 2021). Increased manufacturing output while fewer interruptions and disaster situations are examples of resilience. Sustainability primarily tackles environmental issues, such as energy conservation and resource recycling. Human interests and requirements are put at the center of the manufacturing process, including customization and computer contact, according to the human-centric strategy.

The industrial sector is focused on mitigating negative effects to successfully handle trash and lessen its effects on the ecology in response to the fast rise in environmental contamination brought on by Industry 2.0. Nothing about Industry 4.0 protects the earth. The next industrial transformation has thus been sparked by the need for a technical answer to provide production processes that are pollution-free (Nahavandi, 2019). By decreasing garbage production through the bioeconomy, which creates a pollution-free atmosphere, Industry 5.0 guarantees the viability of society. With the help of technology that allows machines to share and work alongside humans, the fifth industrial revolution (Industry 5.0) has placed a strong emphasis on intelligent manufacturing. With the help of robots and the return of people to manufacturing halls, Industry 5.0 is employing human intellect and ingenuity in intelligent processes. Without worrying about their jobs, people will cooperate and share with the machines, creating value-added services.

By combining several technologies, including artificial intelligence (AI), cloud computing, Internet of Things (IoT), cognitive computing, and cyber-physical systems (CPSs), the Industry 4.0 standard has completely transformed the industrial sector. Making the industrial sector "smart" by linking machinery and other devices that can communicate with one another and manage one another throughout their lifetimes is the primary idea behind Industry 4.0 (Xu, 2020; Li, 2018). Process mechanization is given top precedence in Industry 4.0, which reduces the need for human involvement in the production procedure (Lasi, 2014; Priya, 2021). Industry 4.0 aims to increase overall performance and output by implementing machine learning (ML) to provide understanding between devices and apps (Azeem, 2021; Zhang, 2020). Industry 5.0 is currently being intended as a way to combine strong, clever, and precise technology with the distinctive ingenuity of human specialists. Many technological futurists think that Industry 5.0 will give production one more personal touch (Nahavandi,

2019). Industry 5.0 is anticipated to bring together humans' critical, rational reasoning and highly precise robots. Another significant accumulation of Industry 5.0 is mass customization, which allows consumers to choose individualized and customizable goods based on their preferences and requirements. Industry 5.0 will enable flexibility between robots and humans, greatly boost production productivity, and enable accountability for engagement and ongoing tracking activities. The goal of the partnership between people and robots is to quickly boost output. By giving boring, repetitious tasks to robots or machines and thinking-intensive responsibilities to people, Industry 5.0 can improve the standard of output.

Table 1. *Distinction between this survey and other survey papers.*

Ref.	Enabling Technologies	Impact of 6G	Applications	Future Opportunities	Challenges
(Long, 2020)	X	X	√	X	X
(Al Faruqi, 2019)	X	X	√	X	√
(Ozdemir, 2018)	√	X	√	X	X
(Sachsenmeier, 2016)	X	X	√	X	X
(El Far, 2021)	X	X	X	√	√
Our Survey	√	√	√	√	√

The distinction between this survey and other survey publications is further explained in Table 1. In this study, enabling technology systems, applications and future directions on Industry 5.0 are reviewed. Following is a list of the contributions this study provides. Descriptions of Industry 5.0 are provided based on the existing literatures, which aids in developing a comprehensive concept of Industry 5.0 from various angles. The features of Industry 5.0 compared to previous industrial revolutions are discussed. Industry 5.0-related projects, goods, and groups that create guidelines were investigated. A general basic level of information was given about 6G, which emerged with the Industry 5.0 revolution. Accordingly, the wide uses and objectives are explained. Despite numerous research and development initiatives, Industry 5.0 faces a number of difficulties and issues. The potential research directions are also highlighted for implementation of Industry 5.0.

The remainder of the paper is structured as follows: Section 2 outlines the vision of Industry 5.0. Section 3 presents uses and effective tools in

Industry 5.0. Key Enablers of Industry 4.0 and Industry 5.0 are discussed in Section 4. Discussion, future opportunities and challenges are presented in Section 5. Lastly, Section 6 provides the conclusions.

2. The Rise of Industry 5.0 Vision

The Industry 4.0 is currently taking place. German government listed this project as one of its upcoming initiatives in its 2010 "High-Tech Strategy 2020" action plan. The final goal was to increase automation in smart production and implement automated management with a focus on mass production, as was done during the earlier three industrial revolutions (Tange, 2020). The use of the cutting-edge supporting technologies of the corresponding era, for example, the introduction of various ICT technologies enables the transition from the electronics-based Industry 3.0 to the goal of Industry 4.0 (Aceto, 2019), is one of the major distinctions between different revolutions. Thus, by improving the effectiveness and intelligence of production and robotic processes, Industry 4.0's digital transformation reshapes today's sectors (Chen, 2020). The next industrial transformation, or Industry 5.0, has recently come under discussion in academics and among scholars as a natural progression of the current Industry 4.0 model.

While mass production with minimal waste and increased productivity was a key element of Industry 4.0, Industry 5.0 strives for mass-customized production with zero waste, minimal expense, as well as maximum precision (Yetis, 2020). The idea of Industry 5.0 has yet to fully develop, through examines, for instance, the different meanings and findings made about the Industry 5.0 strategy by eminent industry scholars and practitioners. All pertinent Industry 5.0 ideas place a strong emphasis on the coexistence of humans and robots in order to build an intelligent society in which cobots (robots) handle the less creative aspects of invention and humans handle the more creative ones. In this respect, the European Commission (EC) created the future plans to supplement the industry 5.0 vision with resilience, human-centeredness, and sustainable methods (Industry 5.0, 2023; Industry 5.0, 2021). The next industrial transformation can be realized by enabling people freedom in conjunction with objectives of mass-customization in efficient supply chains, such as flexibility and expandable product variations. This has beneficial effects and advantages for various societal sectors. Figure 1 shows a brief history of industry revolution.

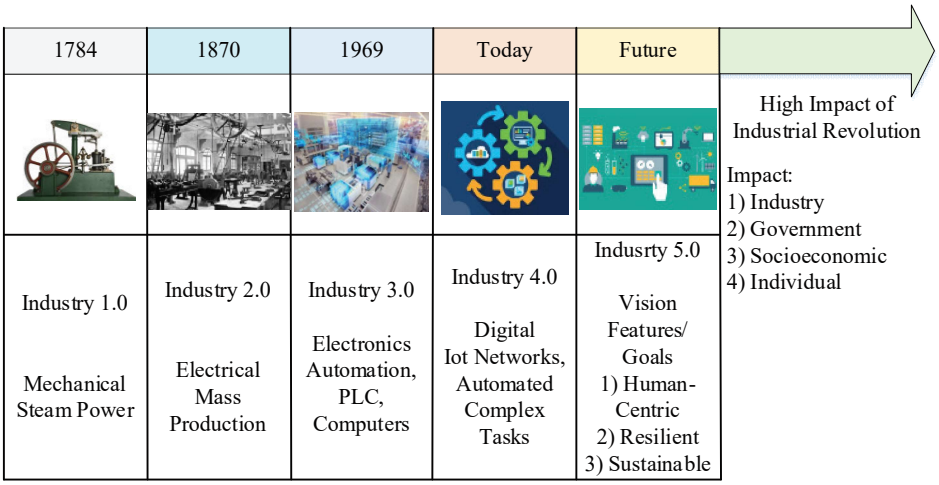


Figure 1. *A brief history of industry revolution.*

Future industries must contribute to the development of solutions for pressing societal issues, such as: 1) preserving the environment and natural resources and combating climate change (sustainability); 2) adopting circular production models; 3) developing enabling ICT technologies; and 4) revising energy consumption regulations to ensure the effective use of natural resources in the event of external shocks, such as the Covid-19 pandemic (human-centric value). The 17 Sustainable Development Goals (SDG) or Global Goals stated in Agenda 2030 of the United Nations (UN) must be realized and enabled by Industry 5.0 vision components (UN, 2017).

By combining both established and cutting-edge methods and technologies, FoFs in Industry 5.0 can offer creative answers to impending social problems. Notably, significant developments in a number of emerging technologies, such as robotics (Xiloyannis, 2021), Industry Internet of Things (IIoT) (Mahmood, 2022), computer vision (Janai, 2020), big data analytics and computation technologies (Ma, 2021), B5G wireless networks (Huang, 2021), and AI (Du, 2020), have made it possible for new industrial applications to be developed that are both vertical and horizontal.

3. Uses and Effective Tools in Industry 5.0

With the integration of cognitive skills and creativity, a number of supporting technological trends, including EC, big data analytics, IoE, cobots, blockchain, and 6G can help sectors boost production and deliver tailored goods more rapidly. Industry 5.0 is an improved production paradigm with an emphasis on interplay between robots and people thanks to these supporting technologies. Intelligent robots are put together to cooperate with people, making human powers more efficient and incredibly simple for both individuals and small companies to manage than ever before. In this part, supporting technologies for Industry 5.0 are briefly discussed.

3.1. Edge computing (EC)

Due to the IoT's rapid growth and the abundance of cloud services, a novel concept known as EC, which permits data processing at network peripheral, has been introduced. EC can be very helpful in the shift to Industry 4.0 as well as in the upcoming Industry 5.0. Expectations for delay expenses, energy life restrictions, reaction time standards, data security, as well as privacy can all be met by EC (Pham, 2020). EC reduces transmission costs and ensures that applications are effective even in distant locations. Furthermore, EC can manage data without transferring it to a public cloud, reducing security worries for crucial Industry 5.0 activities.

3.2. 6G and beyond

6G will eventually be able to provide Industry 5.0 with substantial value-added services. A very dense network of thousands or millions of sensors, cars, and hardware components makes it challenging to construct radio infrastructure. It won't be feasible to satisfy the quickly rising broadband needs due to the robust development of smart infrastructure and prospective apps with existing networks (like 4G and 5G networks) (Shah, 2022; Shah, 2021). The Industry 5.0 transformation can offer improved delay and support high-quality services, as well as comprehensive IoT infrastructure and incorporated AI powers, thanks to the use of 6G and beyond. By supplying intelligent frequency management, mobile EC driven by AI, and intelligent mobility, 6G networks aid in the efficient and effective improvement of application performance in Industry 5.0 applications (Chowdhury, 2020). The requirements of an intelligent information society, which can deliver ultrahigh data speeds, ultra-low delay, ultra-high dependability, high energy economy, traffic capacity, etc., are anticipated to be met by 6G networks for Industry 5.0 apps.

3.3. Cobots

Recent advancements in automation and robotics have made working with computers increasingly important. Due to the incredibly quick advancements in AI and smart technology, it is clear that all devices with computing capabilities have become more intelligent and have introduced a new technology called cobots. Collaborative robots are those created specifically to work alongside humans. Through this collaboration, human skills are improved and made easier than ever for individuals and small companies to automate. Cobots have a lot to give in Industry 5.0. Robots can accomplish their intended task when working with people, which enables them to deliver mass-produced, individualized goods to consumers quickly and accurately. Cobots can be personalized in many ways in Industry 5.0, such as by offering medical services, smart apps that effectively

outline a patient's healthy lifestyle, and medical needs to develop a completely unique health-fitness regimen (Simoes, 2020).

3.3. Internet of Everything (IoE)

IoE is a network of connections between individuals, systems, organizations, and physical objects. Industry 5.0 applications can benefit greatly from IoE by opening up new options (Li, 2021). IoE's developments in Industry 5.0 have the potential to bring about new features, improve user encounters, and benefit sectors and countries. The importance of IoE in Industry 5.0, increasing consumer satisfaction and trust, and generating customized experiences utilizing data produced by IoE. By removing communication route obstacles and lowering delay, IoE use in Industry 5.0 offers a chance to reduce running expenses.

3.4. Blockchain

Industry 5.0 could be greatly improved by blockchain technology. In Industry 5.0, centralized administration of a significant number of diverse linked devices is a key task. By allowing dispersed confidence, blockchain can be used to create autonomous and distributed administration systems. Secure peer-to-peer contact using blockchain technology offers an unchangeable database for keeping documents (Prabadevi, 2021). Also, a segmented and dispersed strategy using blockchains can provide a better degree of security for data and activities. Blockchain technology can also be used to allow data collecting and getting.

3.5. Big Data

Big data is currently a hot topic of debate in both academics and business. It symbolizes a big and varied collection of data gathered from all kinds of sources. Big Data technologies like AI, ML, social networking, data integration, data mining, and so forth are used in many data analysis methods (Mitra, 2021). Industry 5.0 often places a lot of emphasis on big data analytics. Big Data Insights can be utilized by some businesses in Industry 5.0 to better understand customer behavior, which can then be utilized to maximize product pricing, concentrate on enhancing production productivity, and assist in lowering administrative costs. Big data analytics can be utilized to make decisions in real-time to enhance industry competitive advantage with a focus on providing recommendations on prediction results for important events in Industry 5.0 applications.

4. Key Enablers of Industry 4.0 and Industry 5.0

Numerous helpful studies about new technologies that make up Industry 4.0, their debut, and their advantages are currently available. A distinct

understanding of how Industry 4.0 affects business models and groups is sought after by the studies that have surfaced from the literature (Ibarra, 2018). However, it is noted that less work has been put into studying the function of people in the future industry, suitable organizing models, methods for creating long-term value, and social impacts (Tirabeni, 2019). Long-term progress depends on these interconnected elements in terms of sustainability-related problems, technology, people, and their jobs.

Industry 4.0 focused on all newly developed technologies in terms of technology. But as a result of Industry 5.0, some new technologies are getting more attention from researchers, while others are losing their appeal. Again, the growing interest in HMI and AI demonstrates that more emphasis is being placed on using technology as an assist to the routine duties performed by human workers. Due to the widespread adoption of the 5G wireless network in modern society, the Industrial Internet of Things has emerged as a key area of technological study.

6. Discussion, Future Opportunities and Challenges

The majority of sectors, including biological sciences, retail, manufacturing, health care, textiles, medicine, and banking, have embraced Industry 5.0 as a result of its development.

Time-space barriers can be removed in 6G with the aid of AI and holographic communication, allowing for the effective optimization of productivity as long as there is an ultra-low delay communication network. By offering high data rates in interior settings, visible light communication is another potential technology that can satisfy the needs of the healthcare industry. Additionally, the vast quantity of patient medical information needs to be extremely private and properly segmented. All of these situations can be satisfactorily addressed by 6G technologies, which can guarantee stable communication. The Internet of Bio-Nano-Things and the Internet of Nano-Things are thought to be IoT for the future of healthcare, according to current study.

The state-of-the-art indicates that by embracing supporting technical trends like EC, big data analytics, IoE, cobots, blockchain, and 6G, Industry 5.0 plays a major part in a diversity of uses. All of these supporting technologies combine brain abilities and invention to help businesses produce more goods and distribute tailored goods more rapidly.

6.1. Discussion

Industry 5.0 and its merger with AI, IoT, and Big Data were the subject of a research that was published in (Leong, 2020). They propose constructing riskier and more intricate hyper-connected networks, which have the

potential to shape the future of many industries, including the use of digital drugs to track actual drug adherence. In many digital settings, big data accumulations will gain from AI, IoT, as well as Industry 5.0. Additionally, (Javaid, 2020) showed the potential uses of Industry 5.0 in coronavirus disease (COVID) for patient-specific treatment and diagnostics. In order to assist COVID epidemic, they have utilized Industry 5.0 technologies like holography, 4D images, robotic robots, videoconferencing, and smart inhalers. In order to address the issues related to the COVID pandemic's effects, they suggested that Industry 5.0 take on some of the significant challenges (such as patient tracking, automatic personalized treatment, supply chain optimization, raising awareness, digital medicine, drug manufacturing, and crowd monitoring). Furthermore, in the post-COVID period, development of cobot, CHIPBOT (implanted circuits in COVID patients), and CURBOT (currency and bankless systems) can be used for mobile purchases, kidnapping tracing, patient surveillance, and treatment.

A value-sensitive architecture for smart workplaces was suggested in (Longo, 2020). The promise of Industry 5.0 in human-machine symbiosis-based future industry is discussed. Additionally, industrial systems engineering offered answers to the machine's social repercussions on human employees and demonstrated how value-based design reduces problems associated with the application of the symbiosis Industry 5.0. To meet requirements of IoT and Industry 5.0, the managers should have a greater grasp of the innovation ecosystem, business strategy, and design thinking, according to ultimate innovation management paradigm established in (Aslam, 2020). However, the research does not discuss how the structure and safety measures will be implemented once they are integrated with corporate operations.

Better traffic control solutions are still in demand, but Industry 5.0 can significantly progress the industry by combining computer intelligence, human intelligence, and 5G networks with other technologies. When creating a cleverer driverless car, Industry 5.0 can incorporate sophisticated technologies to facilitate communication and teamwork. In addition, the cloth business will gain more from this change by being able to offer clients more customized outfits. Fiber computing (Sherburne, 2020) can be used by Industry 5.0 to create more specialized goods, which will subsequently result in more environmentally friendly cloth production. In order to service clients more personally, Industry 5.0 has a broad variety of uses in almost all fields.

6.2. Challenges

Through the use of a cognitively empowered production process, Industry 5.0 can allow the most individualized client services. Some of the

possible execution issues covered in this part must be resolved for smooth services. Security is one of the possible difficulties. The security risk in diverse data processing and employing cloud services for variegated user and corporate data management must be double-checked as we progress towards more digitalized calculation. While providing customers with tailored and more accurate services, privacy-preserving data interactions, privacy in data gathering, and social problems must also be taken into consideration. The return of human labor to the manufacturing floor may be successful, but there must be effective training provided for both parties in order to address real problems and ensure that human and computer intellect coexist peacefully. By combining human-robot co-working with specialized customer assistance, the issues related to ramping up the users and the production processes must be taken into consideration. In order to prevent possible disadvantages and detrimental social effects on the acceptance of AI, ethical considerations must also be made.

It is essential to create reciprocal confidence in the ecosystem by authenticating the enormous variety of various stakeholders, including IoT nodes, computers, cloud nodes, communication nodes, and joint partner nodes. The Industry 5.0 verification methods should be lightweight to be deployed with IoT nodes, adaptable to link billions of devices, and quantum resistant to withstand uses of quantum computing in the future.

Privacy is a crucial prerequisite for Industry 5.0 apps because the entire ecosystem relies on costly intellectual property, expensive production inputs, and membership administration. To link machinery and people, creators and other partners, and to share tracking and control information, data is transferred over the Internet in Industry 5.0. In order to maintain the confidence of the cloud production environment, such data must not be accessible to malevolent Internet users.

When the system's workload varies constantly, scalability can be described in terms of the system's resilience, adaptability, and reactivity. Scalability in Industry 5.0 refers to a system's efficiency under various working circumstances, regardless of whether there are more or fewer hyperconnected systems present in the network. Industry 5.0 is designed to link and converse with a variety of systems from other companies as well as a variety of people. Scalability is one of the characteristics of Industry 5.0, which is an improvement of Industry 4.0, but it poses a greater challenge when making robots or other machines and people a partner by sharing their task. Using service level signs that have been verified in accordance with the service level goals stated in service level agreements, the scaling can be monitored. This is a crucial issue because non-deterministic development of companies, equipment, and people is another element. Technology providers in the Industry 5.0 ecosystem must be able

to provide service at any capacity, adaptable enough to extend and grow, and provide a low-latency reaction without any data processing delays in order to guarantee scaling. The many inquiries received from the adaptable cloud and dynamic peripheral servers must be processed by AI-based cobots without any unforeseen delays.

To tackle any technology, societal, and management problems, uniformity and regulatory policies must be implemented because a competent worker in Industry 5.0 is anticipated to give a high-value job in production. A competent workforce is imparted by taking into account a variety of management, employee, corporate culture, management infrastructure, and standard policy issues. Inadequate teachers and budgetary limitations make it difficult for people who work alongside cobots to receive the appropriate training, which is the main skill space challenge. By the time Industry 5.0 is completely implemented, there will be a greater need for qualified workers, and the use of new technologies will increase as well. This will necessitate sufficient training for both potential teachers and students. This might encourage public-private collaborations. Reforming the legal framework will also be required. The educated personnel can also support corporate success.

Laws and rules are a key prerequisite for any industrial revolution's complete acceptance. Although there are generally accessible standards for technology, innovation policy, and industry policies, the more particular standard for this new age needs to be implemented. Different rules relating to both the human and cobot must be developed as Industry 5.0 seeks to bring back the human labor force to share and work alongside cobots and clever machines. Without appropriate rules and laws, a number of problems could develop in this co-production setting. Cobots must be distinguished from other machines, such as drones, by regulations that are implemented. Additionally, laws promoting the use of cobots, AI, and other robots in the industrial sector should be developed for more accurate forecasts and advanced coproduction. The implementation will be completed more quickly and will be easier to handle with better laws, regulations, standards, and rules.

7. Conclusion

In this paper, an overview of Industry 5.0's enabling technologies and possible uses is provided. This survey is started by defining a few Industry 5.0 ideas from the viewpoints of the scholarly and business groups. The study on the key supporting technologies of Industry 5.0 was then followed by a discussion on some of the possible uses of Industry 5.0, including digital healthcare, supply chain management, cloud manufacturing, industrial production, etc. The Industry 5.0 transformation and the 6G cellular con-

nectivity revolution will change how the world looks in the future. Industry 5.0 is an idea created to consistently align the productivity of people and robots in the workplace. Industry 5.0, made possible by a variety of new apps and enabling technologies, is anticipated to boost industrial output and client happiness. A number of difficulties and unresolved problems are also discussed that need to be addressed in order to fully actualize the idea of Industry 5.0 in the near future, including privacy, security, human-robot collaboration in a workplace, scaling, and specialized labor.

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