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ROLE OF MATHEMATICS TO BUILD A SUSTAINABLE FUTURE FOR INDUSTRY 5.0

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Abstract

The fourth industrial revolution, in short Industry 4.0 is the next stage in the digitization of the industrial sector and is being driven by disruptive trends including the growth of data and connectivity, analytics, human-machine interaction, and advancements in robotics. For the past ten years, Industry 4.0 consistently addressed both the industry's strengths and weaknesses. Industry 4.0 is limited by the higher productivity that smart manufacturing systems provide. The new version of Industry 4.0 is termed Industry 5.0 and it refers to the fifth industrial revolution and is an emerging concept that builds on the advancements of Industry 4.0. Thus, industry 5.0 is an extension and further advancement of Industry 4.0, which focuses on automation, connectivity, and data exchange in manufacturing processes. Industry 5.0 introduces a new level of human-machine collaboration and emphasizes the importance of human creativity and skills alongside advanced technologies. This study discusses the opportunities and directions of future mathematical research towards Industry 5.0.

Keywords : Industry 4.0, Industry 5.0, Artificial Intelligence, Big Data, Cryptography, Machine Learning, Optimization Techniques, Quantum Computing, Robotics.

I. Introduction

A Series of industrial revolutions brought considerable development in diverse scientific domains, particularly in the manufacturing sector, where Industry 4.0 played a crucial role. Digitization and Industrialization are the needs of manufacturing sectors and are core technologies for the industrial revolution. To change from mass production to customized form, the manufacturing process needs to be made more automated and sustainable so that people can operate the machine more efficiently and persistently. Industry 4.0, also called the fourth industrial revolution usually refers to the developmental process in the management of manufacturing and chain production. Addressing customer needs is the main goal of Industry 4.0, as they have an impact on a wide range of developing fields in every sphere of life including order management, research and development, manufacturing as well as the delivery up to the recycling and utilization of products. Industry 4.0 is a relatively new domain for scientific research[XLVIII, LIV], where the Internet of Things (IoT) along with cyber-physical systems are interconnected in such a way that makes the "things" have full potential to feed the information into it and to transform the manufacturing processes more sophisticated with a combination of software, sensor, processor and communication technology. By taking into account the fact that Industry 4.0 did not pursue the objectives of human centrality, sustainability, and resiliency. Industry 5.0 has been described in accordance with these principles [XXVI, XXIV, XLIV]. Industry 5.0, promoted by the European Commission, strives to move the sector forward in the direction of Europe's 2030 ambitions, where the socioeconomic and environmental implications are of utmost significance. Industry 5.0 recognizes certain tasks, particularly those requiring emotional intelligence, creativity, and problem-solving skills, are better suited for human involvement.
Industry 5.0 aims to build a symbiotic future where humans and machines will work collaboratively. Machines handle repetitive and mundane tasks, while humans focus on innovation, critical thinking, and customer-centric activities. This collaboration allows for the creation of more customized and personalized products and services, meeting the diverse needs of consumers. Key technologies that enable Industry 5.0 include artificial intelligence (AI), robotics, augmented reality (AR), virtual reality (VR), and advanced data analytics. These technologies support human workers by augmenting their capabilities, providing real-time insights, and facilitating intuitive human-machine interactions. Industry 5.0 also recognizes the importance of ethical considerations, sustainability, and social responsibility. It seeks to build an inclusive and sustainable future, through putting an emphasis on the workers' well-being, reducing environmental impact, and guaranteeing equitable access to technology and opportunities. In short, Industry 5.0 represents a shift towards a more human-centric approach to industrial development, combining the strengths of humans and machines to drive innovation, productivity, and societal progress. The purpose of the article is to study the potential future direction of mathematical research towards industry 5.0.

II. Background of Industry 5.0

Industry 5.0 has been extensively studied by researchers in recent times [XXVIII, XVI, XX, XXV, XXIX] and the references therein. A systematic literature on Industry 5.0 is found in the works [I, IX, X, XII, XXII, XXXV, LV]. As such, Industry 5.0 is the integration of digital technologies and artificial intelligence with human capabilities in various industries, including engineering. Industry 5.0 in engineering revolutionizes how engineers approach product development, manufacturing processes, and sustainability. It empowers engineers to leverage advanced technologies, collaborate with machines, and make data-driven decisions, leading to more efficient, sustainable, and customized solutions. The manufacturing industry has already seen the emergence of Industry 5.0 [XLVII] and the literature is also growing rapidly [XXXVIII]. It is important to note that, industry 4.0 is concentrated on automation, digitalization of industrial processes, and AI-driven technologies at the expense of the fundamental values of social justice and sustainability [LIV], whereas Industry 5.0 emphasizes human-machine collaboration and brings the human element back into the manufacturing sector. In the work [XXXVIII], the authors highlighted the difference between Industry 5.0 with Industry 4.0 and also discussed 17 critical points of Industry 5.0. Nahavandi in his paper [XLVII] also affirms the usage of robots and, notably, the fact that in Industry 5.0, robots are expected to become collaborators with human operators, and thus it is the essential distinction between Industry 4.0 and Industry 5.0. In the paper [V], Adel characterizes Industry 5.0 as a paradigm shift based on cooperation between humans and robots, has the same viewpoint, and supports it. In a similar view, Akundi *et al.* [I] noted that the development of a smart society and the introduction of co-working spaces for humans and robots are the main trends of Industry 5.0. Considering that Industry 5.0 is a relatively new concept [I] in the Industrial Revolution, there isn't much consensus on what it means. Maddikunta *et al.* [XLII] pointed out that Industry 5.0 can encourage higher-skilled jobs and bring back the human workforce to industries. This is accomplished by swapping out the minimal machine-human contact that exists in the Industry 4.0 setting for highly collaborative, flexible, and personalized scenarios in the Industry 5.0 context [XV]. Muller [XXIV] claims that other ideas or technologies related to Industry 5.0 include bio-inspired technologies, energy-saving technologies, digital twins, cyber security, and AI. The three final ideas are essential to Industry 4.0 as well, thus they do not emphasize what makes Industry 5.0 unique. According to the results of the bibliometric [XXXIX], the current literature available on Industry 5.0 says very little about energy efficiency and bio-inspired technology. As a result, the human-robot collaboration can legitimately be regarded as the key technology characterizing Industry 5.0 and setting it apart from Industry 4.0. It should be noted that the Industry 5.0 concept, as presented in several publications by the EC's DGRD [XXIV, XXXIII] places more emphasis on the sustainability aspect of the paradigm than on the technological features, giving the planet's resources and workers' well-being on top priority. In contrast to the paper [XXXIII], Breque *et al.* describe Industry 5.0 as a winner-takes-all model that builds a technological monopoly and fails to address the sustainability challenges that are being faced by societies nowadays. For instance, the works of Renda *et al.*, [VII] present decarbonization, the circular economy, and designing out waste as the essential components of Industry 5.0. Applications of industry 5.0 in diverse scientific domains are available in the works [II, III, V, VI, XIX, XXXII, XXXVI, XXXVII, XLII, XLIII, XLVIII, LIII] and the future scenario of industry 5.0 is available in the works [XXX, LI].

III. Mathematics VS Industry 5.0

Industry 4.0 aims to enhance productivity and efficiency through automation and digitalization, whereas Industry 5.0 seeks to integrate technology with human capabilities to create value and address complex challenges. The idea of Industry 5.0 has gradually permeated in many aspects of society, particularly in logistics, security, services, and transportation. Being an all-encompassing discipline, mathematics is vital to the advancement of science and technology. Therefore, attention must be given to the mathematical interactions and questions surrounding such advancements in these domains. Industry 5.0 can have a huge impact on mathematical advancements. Here, we present a few potential areas where advancements in mathematics can contribute to Industry 5.0.

a) Artificial Intelligence

Artificial intelligence (AI) involves emulating human intelligence in machines, encompassing applications like expert systems, natural language processing, speech recognition, and machine vision. The future is poised to witness a significant impact of AI on diverse businesses, as it will automate processes, improve decision-making capabilities, and stimulate creativity. AI has many applications, from personalized healthcare diagnoses to autonomous transportation systems. These diversified applications have the potential to revolutionize our approach to various difficulties. The continued influence of natural language processing and data analysis in several areas, such as banking and education, will bring about a significant transformation characterized by enhanced efficiency and technical progress. Industry 5.0 is characterized by AI integration with traditional industrial processes. It has the potential to contribute to every aspect of the industry, including supply chains, production, design, research, and development [I, IX, XXI, LII]. The use of AI can considerably raise the bar for any industry's quality and requirements. Industry 5.0 aspires to utilize AI to comprehend human demands and be able to foresee environmental impact while adjusting to the current situation. Industry 5.0 evolves a closer collaboration between humans and AI systems, where AI technologies are used to enhance human capabilities and open up new avenues of working. AI plays a crucial role by offering advanced automation, data analysis, and decision-making capabilities. AI-based technologies such as machine learning, natural language processing, and computer vision can process large amounts of data, identify patterns, and make predictions, augmenting human intelligence and improving efficiency in various industries. In Industry 5.0, AI enables automation, where machines can understand, learn, and interpret complex data like humans. This allows for more advanced and flexible automation systems that can adapt to changing circumstances and collaborate with human workers effectively. Moreover, AI-empowered technologies in Industry 5.0 can enhance safety and mitigate risks in high-risk environments. For example, robots equipped with AI-based algorithms can perform tasks that are more faster and physically demanding for humans, reducing the likelihood of accidents and injuries.

b) Machine Learning

Machine learning (ML), which is being a subfield of AI, seeks to improve accuracy by modelling human learning strategies with data and computational models. ML is paramount in engineering since it offers a wide range of tools and methodologies for analyzing and interpreting intrinsic data sets. Engineers can utilize ML algorithms to recognize patterns, make predictions, and optimize processes across several domains, including manufacturing, system design, and quality control. This technological advancement facilitates the automation of decision-making processes, enhancing efficiency and extracting valuable insights from extensive datasets. Consequently, it contributes to improving engineering system design, operation, and maintenance. Mathematics, particularly areas such as linear algebra, calculus, and probability theory, underpin many ML and AI algorithms. Advancements in mathematics can lead to the development of more efficient and accurate algorithms, enabling AI systems to make better predictions, learn from data, and improve decision-making processes in industrial applications. ML algorithms enable computers to learn from data and make predictions or decisions without being explicitly programmed. In Industry 5.0, ML can be used for predictive maintenance, quality control, demand forecasting, and optimizing manufacturing processes. These are just a few examples of advanced mathematical methods that can be applied in Industry 5.0. The integration of these methods with emerging technologies and the availability of vast amounts of data offers new opportunities for data-driven decision-making and process optimization, ultimately leading to increased productivity, efficiency, and quality in the manufacturing industry. One of the interdependent subjects of ML that have been studied and developed for a very long period is AI.

c) Optimization Techniques

Mathematics plays a crucial role in optimization problems, which involve finding the best possible solution among a set of feasible solutions subject to the given constraints and objectives. In Industry 5.0, optimization techniques [XLIX] can be used to improve efficiency, resource allocation, and scheduling in manufacturing processes, logistics, and supply chain management. Advancements in optimization algorithms and mathematical models can lead to significant cost savings and improved productivity. One specific example of optimization in Industry 5.0 is in supply chain management [VIII, XLVI]. Supply chain optimization involves maximizing efficiency and minimizing cost throughout the entire supply chain network, from sourcing raw materials to delivering finished products to the customers. By applying optimization techniques, companies can determine the optimal allocation of resources, optimal transportation routes, and optimal inventory levels, among others. Another area where optimization is crucial in Industry 5.0 is in production planning and scheduling [XXVII]. Manufacturing companies often face complex problems in determining the optimal sequence of operations, assigning tasks to machines, and optimizing production schedules to meet customer demand. By utilizing optimization algorithms, companies can maximize productivity, minimize idle time, and reduce production costs. Furthermore, optimization techniques can be applied to energy management in Industry 5.0 [XI]. With the increasing focus on sustainability and environmental awareness, companies strive to reduce energy consumption and carbon emissions. Optimization techniques can be used to determine the optimal utilization of energy resources, optimize energy distribution, and identify energy-saving opportunities.

d) Big Data Analysis

The first database management system and data centers were developed in the early 1960s to gather and store data, which is when the idea of big data originally emerged. Big data generally represents the broad variety, large volume, and high velocity of data and is typically measured in petabytes or zettabytes. It is simply a large amount of data. Big data analysis is a cutting-edge analytical technique that is used consistently to find hidden patterns in data and link them to specific actions that aid in decision-making. As high-speed internet became more widely accessible over time, an increasing number of physical devices connected to the internet, began gathering a vast amount of user and machine data. The development of ML and AI further increased the growth of data generation, which catapulted the volume of data handled and processed. In other words, all three- big data, ML, and AI are interdependent and rely on one another for their respective purposes. Industries do several analyses, which are basically categorized as descriptive, inquisitive, predictive, prescriptive, and pre-emptive because in some situations the raw data is not feasible to provide any value. Such analysis supports huge enterprises in supply chain management, risk management, new product development, targeted advertising, customer behavior-based product price optimization, and quicker decision-making. Industry 5.0 generates vast amounts of data from sensors, machines, and other sources [I, V, LII]. Mathematics provides the foundation for analyzing and extracting insights from this data. Techniques such as statistical analysis, data mining, and pattern recognition rely on mathematical concepts to identify trends, anomalies, and correlations, enabling businesses to make data-driven decisions and optimize their operations.

e) Simulation and Modeling

Mathematical modelling and simulation are essential tools in Industry 5.0 [XXXI, L]. They allow researchers and engineers to simulate complex industrial systems, test different scenarios, and optimize designs before implementation. They are extensively used in various industries, including manufacturing, transportation, energy, and healthcare, among others. Advancements in mathematical modelling techniques, such as computational fluid dynamics (CFD) or finite element analysis (FEA), can lead to more accurate simulations and help optimize product designs, manufacturing processes, and energy consumption. Systems and procedures in the real world are modelled virtually in simulations. Engineers can able to examine how physical systems will act under various circumstances by using them as a model for their behavior. Engineers can improve the systems for optimal performance and efficiency by varying various parameters and modelling different scenarios. On the other hand, modelling involves creating mathematical models to represent real-world systems and processes. Models can be used to predict outcomes, analyze data, and make informed decisions. In Industry 5.0, modelling is extensively used in data analytics, where it helps organizations to gain insights into their operations, understand customer behavior, and identify new business prospects. Application of simulation and modelling in the contrast to Industry 5.0 can be seen in the design of smart factories. Smart factories leverage the power of advanced technologies, including IoT, AI, and robotics, to create highly automated and optimized production systems. The use of Simulation and modelling techniques allow engineers to design and test these systems in a virtual environment, enabling them to optimize the performance and efficiency of the factory before it is built. Moreover, simulation and modelling in Industry 5.0 are in predictive maintenance. Data analytics is used in predictive maintenance to find possible equipment breakdowns before they happen. Maintenance teams can reduce downtime and increase productivity by identifying the maintenance needs of these machines ahead of time by developing models that predict the behavior of these machines under various scenarios.

f) Cryptography and Cybersecurity

In an increasingly connected and digitized industrial landscape, it is very much crucial to ensure the security and privacy of sensitive information. Mathematics, particularly number theory and algebraic structures, forms the basis of modern cryptography. Advancements in mathematical algorithms and cryptographic techniques can strengthen cybersecurity measures, protecting industrial systems from cyber threats and unauthorized access. For example, blockchain technology secures and transparentises data, which improves cybersecurity in Industry 5.0 [XLV].

g) Quantum Computing

Quantum computing has the potential to completely transform industries in the era of Industry 5.0 [IV], even if it is still in early phases. The core principles of Quantum computing like superposition and entanglement rely heavily on advanced mathematical concepts such as applied linear algebra, probability theory, and graph theory. These mathematical foundations enable the development of quantum algorithms that can solve complex optimization problems and perform calculations much faster than classical computers.

h) Robotics and Automation

The integration of mathematics into robotics is crucial for developing advanced automation solutions. Concepts such as kinematics, dynamics, control theory, and path planning are all based on mathematical principles. Mathematics helps to optimize robotic movements, improve precision, enhance safety, and increase productivity in Industry 5.0 [XV, XXVIII, XXXIV].

IV. Discussions

In section IV, a few examples are provided to explore how the advances in mathematics can contribute to Industry 5.0. As the field continues to develop, mathematics will play an increasingly significant role in the growth of future technology-driven enterprises. In Table 1, the number of documents in the Scopus database is presented subject-wise for the last four years to show research trends of Industry 5.0 toward diverse scientific domains. In Table 2, the number of documents available in the Scopus database with different categories are presented.

Table 1 : Number of documents on Scopus database: Keyword search as Industry 5.0. (https://www.scopus.com)

Subject areas	2021	2022	2023	2024(upto May)
Agricultural and Biological Sciences	01	1	01	18
Arts and Humanities	01	1	01	02
Biochemistry, Genetics and Molecular Biology	02	5	11	07
Business, Management and Accounting	09	39	81	51
Chemical Engineering	02	10	14	27
Chemistry	02	5	09	06
Computer Science	22	124	253	144
Decision Sciences	07	31	84	22
Economics, Econometrics and Finance	02	11	37	08
Energy	03	17	48	20
Engineering	18	134	245	145
Environmental Science	02	14	25	16
Health Professions	00	1	01	02
Materials Science	04	15	13	17
Mathematics	**07**	**30**	**68**	**36**
Medicine	02	7	11	02
Multidisciplinary	01	0	02	02
Neuroscience	00	1	01	00
Nursing	00	1	01	00
Physics and Astronomy	03	20	27	15
Psychology	01	1	06	02
Social Sciences	06	24	51	32

Table 2 : Number of documents typed in Scopus database: Keyword search as Industry 5.0 in Scopus. (https://www.scopus.com)

Subject areas	**2021**	**2022**	**2023**	**2024 (Upto May)**
Journal Article	22	93	184	147
Conference paper	20	92	179	83
Book Chapter	0	10	41	10
Review	3	22	44	26
Editorial	0	1	4	1
Book	0	1	3	1

V. Conclusion

In the context of Industry 5.0, mathematics offers the fundamental foundations and tools required for data analysis, decision-making process, optimization, and guaranteeing the security of different interconnected systems. Therefore, a comprehensive overview of the role of mathematics is essential for a sustainable future towards Industry 5.0. In this paper, we provided a few advanced topics in the era of Industry 5.0, where mathematics will play a potential role in sustainable research and it will help the researcher to get a new avenue of further research in this area. It is to be noted that, the prime objective of future research on Industry 5.0 is to address the practical challenges and opportunities associated with the integration of AI and robotics with human expertise while considering the broader implications for society and the economy. Advances in mathematics underpin many of the key technologies and applications in Industry 5.0, including AI, ML, data science, optimization, cryptography, simulation, and quantum computing.

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Conflict of interest :

All authors declare that there is no conflict of interest in this work.

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