Chapter 2

Artificial intelligence and IoT-assisted sustainable manufacturing for Industry 4.0

Gaurav Srivastava and Devika Sapra
Manipal University Jaipur, Jaipur, Rajasthan, India

Akruti Sinha
North Carolina State University, Raleigh, NC, USA

Mahin Anup
Microsoft India (R&D) Pvt. Ltd., Hyderabad, Telangana, India

Deepak Sinwar
Manipal University Jaipur, Jaipur, Rajasthan, India

CONTENTS

DOI: 10.1201/9781003257714-2

2.1 INTRODUCTION

An industry refers to a part of an economy that loosely produces or manufactures either raw or finished products or provides services. Since the dawn of civilization, humanity has relied on some degree of industrialization to prosper. The advance of a society is indirectly linked to innovative and ingenious changes in its industries. These technological leaps, which led to fundamental shifts, are today described as "Industrial Revolutions" [1]. The 1st Industrial Revolution was primarily focused in the field of mechanization, the 2nd Industrial Revolution revolved around the intensive use of electrical energy and the 3rd Industrial Revolution is characterized by widespread digitization [2]. This provides the background to the current revolution, Industry 4.0, which was traditionally aimed at digitizing operations and gaining benefits. Fueled by the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), computer vision, and data analysis, it enables development to be achieved at much lower costs by using energy and resources efficiently. The usage of interlinked technologies powered by IoT enables Industry 4.0 to be highly cost-effective and free from the traditional manufacturing errors generally caused due to human intervention. Applying the basics of IoT-cloud architecture by using sensors and actuators and processing real-time data will help the whole manufacturing process to come under a single roof, thereby enabling a data-driven approach for manufacturing which will allow future industries to reduce the difficulties experienced during decision-making and facilitate the timely exchange of goods and services in the global supply chain. Combining subfields of AI, such as ML, natural language processing (NLP), and computer vision can help the industry develop more efficient processes and thereby reduce energy use. AI, combined with edge computing methods where the data is stored, processed, and managed directly at IoT endpoints, allows the entire manufacturing life cycle to be streamlined. Further, the application of Industry 4.0 enables an energy-efficient and environmentally friendly approach and helps mitigate the carbon footprint of large-scale industries. The end product of creating sustainable manufacturing can be characterized as being resource-efficient and adaptable to the growing demands of consumers and business partners alike. It delivers the ability to respond flexibly to global industrial failures and disruptions such as the recent CCOVID-19 epidemic crippling the supply chain and causing labor shortages and an unsustainable environment for manufacturing.

Continuing the progress made through the 3rd Industrial Revolution and the usage of advanced digitization has resulted in a new paradigm shift in manufacturing. The combination of Internet technologies and future "smart" technologies results in an entirely new branch of industrialization. Following on from the 3rd stage of the Industrial Revolution, developed countries are now moving towards the fourth Industrial Revolution or, as coined by Klaus Schwab, 4IR or Industry 4.0 [3]. Broadly, this can be classified as the amalgamation of IoT, cloud computing, AI, ML, and data analysis. Current and future manufacturing imagines an efficient and streamlined manufacturing system backed by smart technology. This smart technology entails the integration of the physical setting of the factory with IoT and cloud computing. This unique implementation can thus be called Application pull or Technology push [4]. The integrated platform helps to monitor and predict the parameters and operations in real time. The use of smart machines can analyze and diagnose issues without any need for human intervention.

Industry 4.0 can be distinguished as comprising four key components: cyber-physical systems (CPSs), the Internet of Things (IoT), cloud computing, and cognitive computing [5]. Major components of Industry 4.0 are depicted in Figure 2.1. To turn a physical setting such as a factory site into a "smart factory" all four components need to be integrated, thereby enabling a smart environment for streamlined manufacturing. In a CPS, the physical and digital levels merge. This integration is governed by computer-based algorithms. It enables the user and physical system to carry out homogeneous work and to achieve the desired output. The real-time condition of the object arises from its physical condition which, in turn, provides datasets

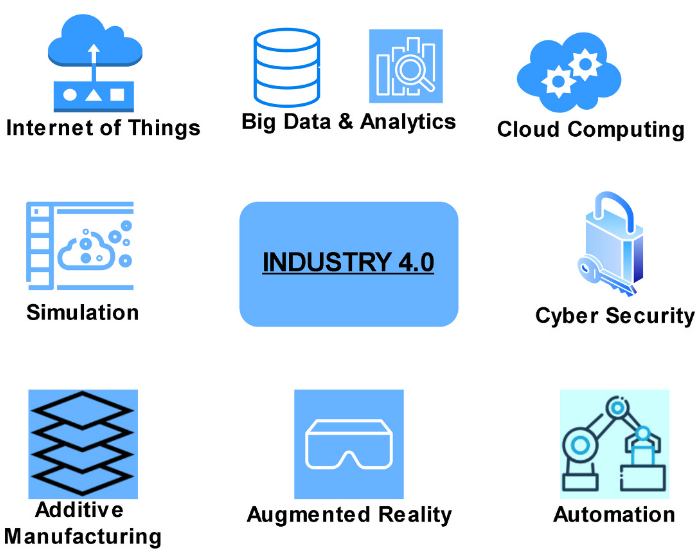

Figure 2.1 Components of Industry 4.0.

that are recorded digitally. This high level of integration can be useful for high productivity. IoT involves the connection of various devices to the Internet and exchanging data. It allows users to connect and interact with various objects and to monitor and control them remotely [6]. Cloud computing refers to a shared pool of available computer resources that can rapidly be used to manage and compute large datasets. It can also be deployed to achieve economic results for the manufacturing site similar to a public utility. Cognitive computing uses AI and ML to better predict accurate models of human response to a stimulus.

2.2 RELATED WORKS

The intelligent manufacturing structure, as defined in Jena et al. [7], is the vertical integration of various components such as industrial networks, clouds, and supervisory control terminals that perform various functions, including production, maintenance, energy consumption, water consumption, and so on. Factories optimize resource utilization and eliminate all sorts of waste to boost sustainable production. Also included is detailed information on the system architecture for Industry 4.0. This model was tested for a year at a cement plant to see how it performed. Findings showed that total production increased by 13.24%, process waste decreased by 12.79%, overall equipment effectiveness (OEE) increased by 12.94%, total downtime decreased by 30.58%, mean time between failures (MTBF) increased by 24.68%, mean time to repair (MTTR) decreased by 25.58%, customer complaints decreased by 30%, rejection decreased by 71.7%, and, finally, specific energy consumption decreased by 71.7%.

In Jung et al. [8], the authors attempted to apply various ML algorithms for quality prediction in injection molding production. Two major elements driving Industry 4.0 are automated data gathering from machines and the application of ML algorithms to the obtained data for automated quality prediction or problem detection. Regression, Tree-Based, SVM, and autoencoders, among other commonly used ML techniques, were compared. The data for this study came from a huge injection machine dataset acquired from actual injection molding manufacturing at Hanguk Mold, a South Korean company. When evaluating the accuracy, precision, recall, and F1-score, the autoencoder models surpass the competition. The molding temperature, hopper temperature, injection time, and cycle time parameters were all found to have a significant impact in feature testing.

In Kumar et al. [9], the goal of the study is to create a big data analytics framework that optimizes the maintenance schedule using condition-based maintenance (CBM) and increases forecast accuracy to measure the remaining life prediction uncertainty. Based on feature engineering and a fuzzy unordered rule-based induction technique, they present a two-phase prediction-based maintenance big data analytics framework for the optimization of the maintenance schedule. They use feature engineering on the available gas turbine dataset in the first step. This introduces new variables, then focuses on observations that are much higher than the rest of the samples, before training a fuzzy classifier with the best prediction accuracy of the backward feature elimination approach. The outlier value is removed in the second step, and the target value is replaced by the predicted value of the trained fuzzy classifier. The experimental results are based on a large dataset obtained by a sophisticated gas turbine propulsion plant simulator.

In Quan et al. [10], the study introduces PCDEE-Circle, a systematic development framework that focuses on the contribution of human–robot collaborative disassembly (HRCD) to economic, environmental, and social sustainability. Perception, cognition, decision, execution, and evolution are the five phases of the PCDEE-Circle, which are reflected in one outward circle and two internal circles. A detailed enabling system for HRCD is also offered, along with a set of advanced technologies, such as the cyber-physical production system (CPPS) and artificial intelligence (AI). The systematic approaches for HRCD also consider deep reinforcement learning, incremental learning, and transfer learning. Using a case study, the paper demonstrated multi-modal perception for ABB industrial robots and the human body, as well as sequence planning for an HRCD task, and eventually realized a distance-based security approach and motion-driven control mode, using a case study. It demonstrates the feasibility and effectiveness of the proposed HRCD techniques and proves the systematic framework's functionality.

In the Industry 4.0 vision, Leng et al. [11] explores the landscape of blockchain-enabled sustainable manufacturing. From two viewpoints, namely the production system and product lifecycle management, this article examines how blockchain might overcome possible challenges to attaining sustainability. The survey begins with a review of the literature on these two views, followed by a discussion of the current state of research in blockchain-enabled sustainable manufacturing, which provides fresh light on pressing concerns related to the United Nations' Sustainable Development Goals. The authors discovered that the blockchain-enabled transformation of a sustainable manufacturing paradigm is still in the hype phase and is on its way to full acceptance. The poll concludes with a discussion of the obstacles that blockchain-enabled industrial applications face in terms of methodologies, societal barriers, standards, and legislation. The study ends with a consideration of the obstacles and societal constraints that blockchain technology must overcome in order to establish its long-term viability in the industrial and corporate worlds.

Research outlining the sustainable manufacturing strategy in terms of principles, implementation procedures, and assessment methodologies is offered by Kishawy et al. in [12]. Here the author addressed the sustainable manufacturing strategy in terms of principles, implementation strategies, and assessment methods. The needed sustainable aim is provided by the interplay of the three sustainable levels (process, product, and system). The author stated that decreasing energy consumption, restricting waste, boosting product durability, reducing environmental and health issues, improving product quality, and producing renewable energy supplies are the main objectives in establishing a sustainable manufacturing system. To attain these objectives, several prerequisites (e.g., approach, methods, data, study, and integration) are required. In addition, implementing the sustainable manufacturing strategy necessitates the use of various design elements. Design for environmental effect, design for resource use and economy, design for manufacturability, design for functionality, and design for social impact are among these considerations. Furthermore, the author stated that there are five primary steps that must be completed in order to build a successful, long-term system. Designing work practices and maintenance, process optimization, raw material substitution, implementing new technologies, and developing new product designs are among these steps.

By mapping and summarizing existing research efforts, identifying research agendas, and identifying gaps and opportunities for research development, the systematic review in Machado et al. [13] aims to identify how sustainable manufacturing research contributes to the development of the Industry 4.0 agenda and for a broader understanding about the links between Industry 4.0 and sustainable manufacturing. This paper contributes to Industry 4.0 research by demonstrating how sustainable manufacturing concepts and the use of new technologies can enable Industry 4.0 to have positive impacts on all sustainability dimensions in an integrated manner, as well as supporting the implementation of the Industry 4.0 agenda in the following areas: developing sustainable business models; sustainable and circular production systems; and sustainable supply chains. The findings indicate that the area is genuine but not consolidated, and that it is changing as a result of the emergence of new business models and the integration of value-creation chains. The findings also allowed for the creation of a research agenda and scenario for the field's future growth, with a focus on more normative studies on the procedures of implementing the Industry 4.0 agenda. This study is not intended to give an in-depth analysis on specific subjects, and its limitations stem from the small number of publications examined, the decision not to apply statistical analysis, and the failure to explore cross-disciplinary problems that may be generated by other academic disciplines.

2.3 SUSTAINABLE MANUFACTURING

Sustainability has been defined in a variety of ways and can mean different things to different people. Sustainable development is a significant goal in human development since sustainability is becoming an increasingly crucial prerequisite for human activities [14]. At its core, sustainable development is the belief that in the development process, social, economic, and environmental concerns should all be addressed simultaneously and comprehensively. Engineering, manufacturing, and design are just a few of the industries where the notion of sustainability has been used. The topic of sustainability is becoming increasingly important to manufacturers. Sustainable manufacturing arose from the notion of sustainable development, which was coined in the 1980s to address concerns about the environment, economic development, globalization, inequity, and other aspects [15]. Recognizing the relationship between manufacturing operations and the natural environment, for example, has become a critical aspect in industrial societies' decision-making [16]. Production process comparisons for the volume/variety matrix of the goods have traditionally been included in manufacturing plans. Today, manufacturing strategies often take into account goods and processes, as well as other characteristics such as habits, in order to combine organizational and philosophical elements into the strategy. Environmental sustainability, economic sustainability, and social sustainability are the three pillars of this approach. As part of a manufacturing supply chain, environmental sustainability entails reducing carbon footprints, water usage, non-compostable packaging, and wasteful operations. If beneficial adjustments are made to this pillar, it can save money for many firms while also contributing to environmental sustainability. Economic sustainability, in turn, entails giving businesses and other organizations incentives while still adhering to all sustainability rules. To be successful throughout time and be prepared for the future, a company must be profitable and generate enough revenue. Companies should adapt and make a profit by pursuing a sustainable approach, rather than producing money in any way and at any cost. The protection of people's health from pollution, fair working conditions, and fundamental access to resources without compromising the quality of life and fair remuneration are all examples of social sustainability. This pillar also includes education, such as teaching people about sustainability and the effects it has on them individually, as well as the hazards it might bring. It all boils down to training the next generation for success while also keeping a healthy lifestyle. Without realizing it, each of us, including you… has a significant impact on the existing and future environmental and social conditions. We must adapt, embrace change, and recognize that sustainability is the path to a prosperous future.

2.3.1 Need for sustainable manufacturing

Sustainability is good for everyone's future. It has numerous short- and long-term benefits, and our Earth's ecology cannot function without more sustainable measures being taken. To exist, all living beings rely on the resources of the planet Earth. Consumers, brands, and corporations will ruin