Recent Applications of Computing and Mobility Technologies to Modern Manufacturing

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***Abstract*—The highly competitive nature of manufacturing industries led to several improvements to reduce costs and improve product quality. The modern manufacturing industries integrate several computational and communication technologies for competitive advantage. This paper describes the evolution of manufacturing processes that led to the digitization of factories along with their characteristics, benefits, and challenges. The applications of main computational technologies (such as cloud computing, robotics, internet of things, augmented reality, Blockchain, big data, and artificial intelligence) in streamlining smart manufacturing are explored. Application of the latest computational technologies imposes stringent requirements on data rates, latencies, transmission reliability, and coverage of communication technologies. The fifth-generation (5G) mobile communications technology has the potential to meet these requirements. This paper discusses the characteristics of 5G and how they help in realizing future manufacturing systems.**

***Index Terms*—Manufacturing, Industry 4.0, Industrial Revolution, Computing, Mobility**

I. Introduction

For centuries, human beings have been actively consuming various kinds of goods that range from the food that we eat to the clothes that we wear. Unfortunately, a majority of these essential goods are not readily available to be consumed directly. This is because these goods are not the raw materials that are found in nature. But instead, they are the final products that are obtained after the processing of the raw materials has been completed. Therefore, these challenges led to an innovative process called manufacturing.

The role of manufacturing is to convert the raw materials into consumer goods. In its earliest form, it was carried out by a single craftsman who would take the help of their assistants or work animals. However, this method could not cope up with the rapid increase in the human population. An alternative method was required to manufacture goods on a large scale. These challenges gave rise to the beginning of the industrial revolutions. Fig. 1 illustrates the four phases of the industrial revolution.

The introduction of mechanization marked the start of the first industrial revolution - industry 1.0. Steam and water-powered machines were developed to replace human labor to improve production capacity. This was later replaced by industry 2.0 that designed machines that worked on electrical energy which helped to massively increase the work rate and lower costs. This is because unlike water and steam-powered machines, electrical machines proved to be more efficient and less resource hungry. In order to further improve the process of mass production, the first assembly lines were also built during that time. Later industry 3.0 started the use of electronics and computers to automate the manufacturing process. This helped to reduce effort, gain higher speed and accuracy. This was later accompanied by industry 4.0 which is the current era of the industrial revolution.

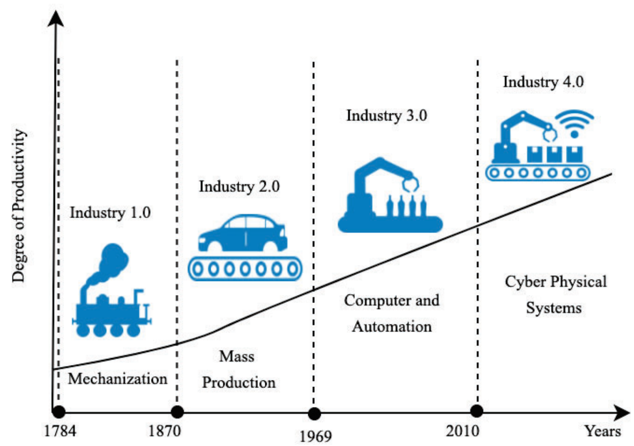

Fig. 1. Evolution to Digital Manufacturing.

Industry 4.0, also known as manufacturing 4.0 is a switch to digital manufacturing. It is commonly known as the era of Cyber Physical Systems (CPS) that comprises of intelligent machines, storage systems, and manufacturing facilities. This involvement of CPS helped to gain a fully automated system that does not require human intervention. This means that the exchange of information and the implementation of actions can be performed autonomously. This switch to no human intervention helped to massively boost the manufacturing rate and improve the quality of goods. Therefore, the start of industry 4.0 helped to improved efficiency, flexibility, and working conditions of the manufacturing industry.

In this paper, we present a review of the impact of modern manufacturing in two areas: computing and mobility. The primary goal of the paper is to study the latest contributions of industry 4.0 in the manufacturing sector by exploring different researches related to it. In addition to this, the paper also discusses possible future trends that can help to further improve manufacturing.

II. Modern Manufacturing

The transition from traditional manufacturing to modern manufacturing was crucial to ensure the growth of the manufacturing sector. Modern manufacturing, commonly known as industry 4.0, aims to boost efficiency, increase output, improve quality, ensure safety and security. As compared to traditional manufacturing, modern manufacturing differs in terms of the method used to facilitate production. That is, it requires minimal to no human involvement to complete the desired tasks. Table. I illustrates some of these key differences that distinguish the two manufacturing methods.

TABLE I
Comparison of Traditional and Modern Manufacturing

Traditional Manufacturing	Modern Manufacturing
Machines are automatized	Machines are autonomous
Focuses on mass production	Focuses on customization
Requires traditional craft skills	Requires latest high tech skills
Enhances cost-efficiency	Enhances flexibility
Expands floor space	Expands IT and infrastructure
Prioritizes productivity	Prioritizes customer satisfaction

The main role of industry 4.0 is to help manufacturing industries to create connected systems, so that information can be processed, analyzed, and used to execute necessary actions. The manufacturing environment that comprises of such a system is called smart manufacturing. As depicted in Fig. 2, smart manufacturing comprises of several components that help to rapidly enhance the manufacturing process.

Collaborative robots, also known as Cobots, provide manufacturers a safe, efficient, and flexible automation system that supports human labor. It also provides improved working conditions in the industry and encourages humans to resort to satisfactory jobs in the industry. Wearables such as smartwatches, exoskeleton, smart glasses, etc., ensure the safety of the human labors by preventing injuries. To assure the quality of manufactured products, computer vision is employed to examine faults in the products that could be missed by humans. Smart sensors help to manufacture better products at a faster rate and at lower cost. Industrial Augmented Reality (AR) helps to enhance manufacturing operations, productivity and the training offered to the workers. Unmanned trucks would be used to deliver the final goods without the need of a driver. This thereby would help to boost the efficiency in terms of delivering the goods, reduce traffic congestion and accidents by operating during the off-peak hours. Predictive analysis ensures the smooth operation of machines by analyzing the patterns made by past machine failures.

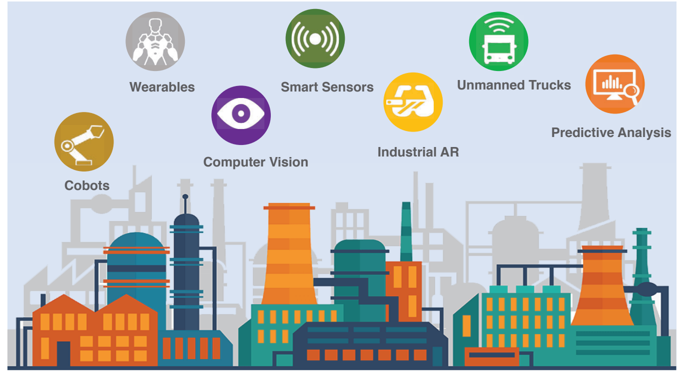

Fig. 2. Smart Manufacturing Components [1].

A. Characteristics

Modern manufacturing is distinguished by a few principal characteristics. Mentioned below are the principal characteristics of modern manufacturing [2]:

- **Interoperability**: This refers to the ability to connect devices, sensors, machines, and people with one another via the Internet of Things (IoT) or Internet of People (IoP) to communicate, exchange information, and coordinate tasks.
- **Decentralized Decisions** : This refers to the capability of Cyber Physical Systems (CPS) to make decisions on their own and autonomously execute tasks. In case of any conflicts that might arise with the intended tasks. These tasks are then sent to be handled by higher levels.
- **Technical Assistance** : This feature provides support to humans through extensive aggregation and visualization of data. This helps to make better decisions and find solutions quickly to solve problems. Furthermore, technical assistance also involves the ability of CPS to support humans by executing tasks that are tiresome or dangerous to perform.
- **Data Transparency**: This feature allows information systems to create virtual copies of the physical world by improving digital plant models with sensor data. However, the aggregation of raw sensor data to compatible context data is required.

The above characteristics of modern manufacturing helped in the improvement of manufacturing processes efficiency and throughput, overall profit, product quality, and customer service.

B. Challenges

Despite having several features and benefits, modern manufacturing faces the following major challenges:

- **Lack of Skilled Labor** : Manufacturers require the employment of skilled labor to complete tasks such as programming, supervising, and managing automated systems. And as the global population rises, it is expected that out of the 4.6 million manufacturing jobs available in the future around 2.4 million of them will be still vacant [3]. This is because of the fact that less focus has been given to the training of these jobs. To solve this problem, manufacturers must offer existing and new employees, special training sessions and programs with promising incentives to encourage the learning of the required skills.

- **Rapid Technological Advancements** : Latest technologies like IoT, advanced robotics, 3D printing, etc., can overwhelm the manufactures on which technology should be invested upon and whether investing in them was the right decision to foster the manufacturing business. In order to be competitive in the market, manufacturing industries need to be careful while deciding investments in the right technologies. Avoiding technology is not an ideal solution as this would make the business fall behind as compared to its competitors. The best solution would be to include stakeholders and employees to discuss investment plans about which technologies are worth to be invested upon [4].
- **Predicting Future Demands** : Even during this present time, most of the manufacturing industries still face the challenge of predicting future consumer demands. The lack of utilization of the latest reporting tools in the manufacturing industries is the cause of this challenge. Without these tools, it is difficult for manufacturers to have an idea of future requirements. This results in the failure of meeting up with the consumer demands, thereby resulting in a huge loss for the manufacturing business. In order to solve this problem, manufacturers need to employ promising reporting tools to make better predictions of future market demand. Apart from this, it is also important for manufacturers to take into account external activities like marketing trends, currency exchange rates, fuel prices, etc. Thus, by taking both of these solutions steps into account, manufacturers would be able to ensure that the sales and marketing teams are always up to date with the current market trends and expenses [4].
- **Cybersecurity**: As technology continues to evolve, the growing need for cybersecurity also arises. The majority of manufacturers rely on old security systems that are insufficient in detecting the latest current cyber attacks and threats that the industry can suffer from. This makes the system vulnerable to cyber-attacks and dangerous breaches, thereby allowing hackers to gain unauthorized access to the vulnerable components of the manufacturing industry [5]. To avoid this challenge, manufacturers need to secure their network, routinely update the security software, and also educate employees on the basic concepts of security attacks and relevant preventions attacked.

The next sections discuss the major components which play a key role in the development of modern manufacturing. These components could be mainly classified into two major categories: computing and mobility. With the integration of the components present in these categories, a high-tech ecosystem of smart devices can be achieved which would revolutionize the way manufacturing industries works. This thereby helps to create an efficient production and optimized workplace.

III. Integration of Computing in Modern Manufacturing

As described in the previous sections, computing plays a predominant role in the implementation of various processes involved in the manufacturing of products under the umbrella of Industrial Revolution 4.0 (IR 4.0). We will now identify the prominent computing technologies, approaches, and frameworks that are currently used in enhancing the performance of industrial manufacturing. Also, we will provide the benefits, challenges, and use case scenarios (a car manufacturing plant) of these specific technologies for different process management stages involved. Figure 3 depicts eight important computing technologies applied to the IR 4.0 [6]. The technologies are now described in the following paragraphs.

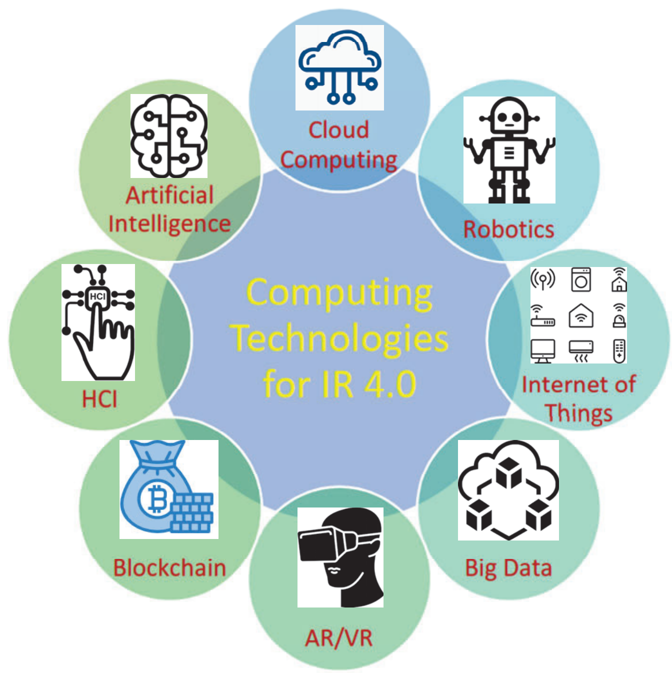

Fig. 3. Applied Computing Technologies for IR 4.0.

- **Cloud Computing**: It is an information and communications technology that brings with it numerous features and benefits for the manufacturing industry. The ubiquitous availability of computing processing power, storage space, data transmission, and networking capabilities coupled with low setup cost, high availability and reliability, and pay-as-you-go subscription model has attracted various businesses to proactively adopt the Cloud Computing model to their benefit. It provides customized services like Manufacturing as a Service (MaaS) and Logistics as a Service (LaaS) to bring about intelligence and automation in the manufacturing processes [7]. This integration helps in achieving increased production, reduced processing time, and high-quality products. However, two major issues that need to be taken into consideration are data privacy and losing control over performance data which might hamper the productivity and competitiveness in the market (e.g. sensitive data regarding the car engine design specifications).

- **Robotics**: One cannot imagine a modern manufacturing industrial plant without the involvement of automated and self-configuring robots which perform the various significant tasks like Simultaneous Localization and Mapping (SLAM), grasping and navigation [8]. Numerous benefits of robotic systems can be utilized in the manufacturing of products, such as repeatable precision, consistent quality of the finished product, continuous work without getting tired, and processing multiple tasks simultaneously. It is common to utilize the cooperative learning feature of multi-robot systems to collectively optimize the output of various complex processes through improved accuracy and throughput. In spite of these benefits provided by automated robots, some challenges do exist in managing proper and safe human-robot interaction, lack of industrial robotics standards and providing reliable self-learning capabilities through machine learning approaches (e.g. a robotic unit may eventually harm a human during a semi-automated car assembly line in the absence of a safety standard).
- **Internet of Things**: In the fourth industrial revolution (IR 4.0) context the automated manufacturing process must consist of a multitude of sensors and actuators. The sensors are used for monitoring and collecting data from physical machines consisting of various functional parts. The actuators are the physical devices that enable the movement of the complex mechanical parts in response to an input excitation. These sensors and actuators are ensembled into the Industrial Internet of Things (I-IoT) which are interconnected through some wired or wireless connection mechanisms for sensing, gathering and processing of data (e.g. SCADA systems). Factory automation and process monitoring and control through I-IoT enables improved productivity, efficiency, safety and intelligence [9]. At the same time, the system manager should be aware of the challenges which come along with this automated monitored system like, constrained energy of the operating sensors, lack of communication standards, scalability issues of the sensor networks and security mechanisms under impending threats from hackers (e.g. a compromised sensor network sink could make the associated car chassis production unit halt its operation resulting in significant economical losses).
- **Big Data**: In general an industrial manufacturing system consists of various components integrated into a single entity to achieve a particular intended function (e.g. a car manufacturing plant). These components are also the source of data that can be structured, semi-structured and unstructured in nature and require time and money to collect, store, manage, share, compute and analyze to derive valuable information. Such a scenario results in what is termed as Big Data, where the manufacturing resources (e.g. material, equipment, environment and product), information systems (e.g. CAD/CAM/CAE systems, ERP systems and CRM systems) and the IoT systems (e.g. sensors and actuators) produce significant volume, variety, velocity and value of data [10]. Even though such Big Data resources incorporate intelligence and optimization to the IR 4.0, they do have the challenges in terms of storage, retrieval speed, model learning and inferencing capabilities (e.g. building a Digital Twin from Big Data of a car engine design requires significant computing and visualization resources)
- **Augmented/Virtual Reality**: With the advent of the IR 4.0, the human workforce associated with the industry has to quickly and efficiently get accustomed to the rapid changes of technology used for various tasks in the industrial plant, such as assembly, maintenance, quality control and material handling [11]. In order for the human operator to rapidly and sufficiently understand these tasks, Augmented/Virtual Reality (AR/VR) tools can be of immense help. Augmented Reality Smart Glasses (ARSG) for example can provide relevant ”virtual” information about a ”real” material or equipment the human operator has to work with. Also, it can provide context-aware information which is presented to the operator in real-time. As a matter of fact, BMW is using AR devices as visual guidelines for the operator to see and hear the instructions about how to repair a car. However, this technology too has its own challenges in terms of proper design of the AR equipment which include number and complexity of sensory inputs, ease of usage, battery life, processing, storage, memory, and connectivity considerations.
- **Blockchain**: Since the industries under the IR 4.0 scenario have a distributed setup, where multiple geographically distributed units of the same company may operate simultaneously, there is a need for decentralized applications which are able to track and store transactions performed by the users and machines. Blockchain technology is an excellent choice for such applications that can provide increased security, data reliability and transaction authenticity [12]. In a specific application of Blockchain to I-IoT based smart manufacturing, certain issues may crop up, like transaction latency, Blockchain size and throughput restrictions, which may hamper the achievement of certain prior real-time targets. Also, it has been observed that Blockchain-based systems are prone to Sybil attacks or boycotting of the transactions by a majority of the group members rendering it useless (e.g. use of smart contracts in two different processes of car manufacturing (billing and quality check)).
- **Human-Computer Interaction**: In spite of the introduction of latest technologies in the smart manufacturing domain, human involvement cannot be completely ruled out. Not all the tasks can be performed by machines or robots no matter what level of automation or intelligence is incorporated in their design and implementation

(e.g. some of the tasks like creativity, real-time decision making, responding to emergencies require human intervention). Thus, the industrial workspace needs to be shared between the humans and the computer operated machines requiring incorporation of HCI technology. The safety of the human operator is of prime importance when it comes to designing HCI systems for a specific application [13]. Certain other considerations include the types of sensory interactions, the task and the machine environment, the input and output data formats, interface design and the ease of use. One example of HCI that could be used in a car manufacturing industry is the airbag quality inspection where the operator can monitor the final product without actually sitting in the car.

- **Artificial Intelligence**: The vast amounts of data that gets generated from the IoT-based IR 4.0 setup, can be effectively used to extract insights for improving production efficiency and intelligent automation. Artificial Intelligence and Machine Learning can play significant roles in learning models from this Big Data, which can provide interesting insights into hidden patterns and develop predictive mechanisms for achieving the goals of smart manufacturing. Different learning approaches like supervised, unsupervised, semi-supervised and reinforcement learning can be effectively used at various stages of the manufacturing processes [14]. However, certain challenges of non-representative data, missing data, overfitting, underfitting, significant delays in model learning time and real-time model updating can have a negative impact on AI-based approaches for automated and intelligent manufacturing. One of the applications of AI in the car manufacturing industry could be to predict complex interactions between production units and hence automate advanced parts requests.

The above-mentioned computing technologies do have a significant role to play in the fourth industrial revolution scenario by achieving increased production, quality improvement, efficiency, material management, and improved revenues. However, certain challenges also exist with each and every technology which researchers need to address. The use case scenarios presented above also give insights into the practical applications of these technologies to IR 4.0 setup. With progressive improvements and by proposing solutions to the above-mentioned challenges, there is definitely a bright future of these technologies to be applied and integrated for achieving the goal of smart manufacturing.

IV. Integration of Mobile Communications in Modern Manufacturing

Modern manufacturing processes are continuously digitized to realize the ”smart manufacturing”, which is achieved by utilizing several technologies such as smart sensors, machine-to-machine communication (M2M), augmented reality (AR), big data, and IIoT. These technological changes impose higher demands on communication technologies. Some of the communication requirements are described in Table II.

TABLE II
Communication Requirements of Smart Manufacturing.

Requirement	Rationale
Connections	IIoT requires many devices to be connected to the network, and thus the number of connections will be high
Coverage	All the shop floor and manufacturing facilities need to be covered, so a ubiquitous coverage is needed
Latency	Many M2M and real-time control systems need the latency to be less than 1ms
Data rates	Systems like Digital twins, AR/VR impost high date rates (of more than 25Mbps)
Reliability	System and process control is done remotely, so a channel with low error rates is needed
Security	Many critical operations are done through the digitized processes, so the communication security is of utmost importance

Smart manufacturing tends to connect many more devices and components to cyberspace. Wired networks cannot provide connectivity to all devices because of obvious difficulties in laying cables. Wireless connectivity is more preferred in smart manufacturing facilities, especially in dynamic production environments. Existing 4G mobile communication technology cannot meet the requirements of modern manufacturing. 5G mobile communications technology is designed with various valuable features, including user-centered architecture, millimeter-wave network, and splitting of control and user planes. This gave many significant advantages, including magnitudes of increase in bandwidth, the number of simultaneous connections and data rates, and lower end-to-end delay [15].

All the three main heterogeneous services that 5G promises to support have several direct applications in modern manufacturing practices. These services are ultra-reliable low-latency communications (URLLC), massive machine-type communications (mMTC), and enhanced mobile broadband (eMBB) [16].

The eMBB offers great high-speed communication experience with high spectral efficiency, bandwidth, and data rate service. They support peak data rates with enduring connections. Thus, eMBB helps in supporting applications such as VR/AR-based design, assembly, and monitoring of products. Similarly, it helps remote monitoring and maintenance of machinery and tools. Cloud computing-based manufacturing processes will also benefit from eMBB service.

The mMTC service, with high coverage, more power efficiency, and support for devices, gives the capacity to connect all available devices and let collaborate and function sensibly. Such high-density and large-scale M2M communications with occasional transmissions of small payloads can promote several intelligent services for modern industries. This service is useful in real-time data collection of manufacturing processes, products, and equipment; similarly, very useful in the identification and location of tools and products.

The URLLC with low data error rate and latency supports communication of small payload with high-reliability from limited terminals. This service enables efficient collaborative-

TABLE III
5G APPLICATION USE-CASES IN MANUFACTURING INDUSTRY.

Service type	Characteristics	Use Cases
URLLC	Offers highly reliable transmissions with low latency	Trajectory planning, industrial automation control, mobile robotics, remote manufacturing.
eMBB	Offers High bandwidth/data rates with moderate reliability	Cloud MES, Holographic projections, 3D ultra-high-definition video surveillance, and AR-based Human-Machine collaboration.
mMTC	Support large number of IoT devices that intermittently send data	Smart sensor reading, smart monitoring, and process automation.

manufacturing and cooperation between man-machine and machine-machine. In particular, in harsh environments, when multiple robots collaborate to accomplish manufacturing tasks reliable low latency communication is required. Table III shows few example use-cases for each 5G service type.

V. CONCLUSION AND FUTURE TRENDS

This paper has discussed how several latest computational technologies such as cloud computing, robotics, internet of things, augmented reality, big data, and artificial intelligence are driving modern manufacturing industries. It further discussed how 5G wireless technology with its proposed features will satisfy the data rates, latency, flexibility, and reliability requirements to support smart manufacturing. Nonetheless, more work still needs to be done to support and sustain the benefits offered by the latest computational and communication technologies to the modern manufacturing industries.

The future manufacturing systems will continue to use many more sensors to collect the data from cyber-physical systems. However, to derive useful information from large amounts of data, advanced big data modeling and analytics software are necessary [17]. Devising techniques that will convert the manufacturing data into useful smart data for proper planning, devising, administration, monitoring, and smart decision making of manufacturing processes.

Similarly, future manufacturing systems will necessarily consider green computing. The increased use of computing, communication, and IT resources will elevate energy consumption and green gas emissions. Hence, inevitably future manufacturing systems will be designed to reduce the environmental footprint. Several measures, such as integrated renewable energy resources, improved data processing/analysis algorithms, and reusable sensor technology should be employed.

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