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Enviable roles of manufacturing processes in sustainable fourth industrial revolution – A case study of mechatronics

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ABSTRACT

Industrial productivity in terms of manufacturing processes has witnessed dramatic increments through advances in technology, right with the ascendance of steam power as the driving force in the manufacturing industry heralding the first in Britain in the early 1800s to the introduction of mass production made possible through electrification of factories to replace all other sources of energy previously used and the use of the assembly line in the early 1900s to the automation of manufacturing processes in the 1970s by introducing electronics and information technology. Currently, we are in a time when new digital technology (the Internet of things and cyber-physical systems) is on the rise and this is going to be the next revolution in industrial processes commonly called the fourth industrial revolution. This research thereby reviews the enviable roles of manufacturing processes in a sustainable fourth industrial revolution having a deep overview in mechatronics applications.

1. Introduction

Mechatronics is a relatively new field of engineering which combines elements of electrical engineering, mechanical engineering, electronics engineering, and information technology [1]. Mechatronics systems are made up of components of mechanical, control, electronic, and computer systems with it consisting typically of using motors to drive their workloads with the motions by which the workloads are carried out and speed at which it is accomplished are controlled by the computer system [2]. Cyber-physical systems (CPS) is a term used to embody a network of intelligent interacting components connected over the internet, otherwise called the Internet of Things (IoT) [3] CPS possess sensing, communicating, computing and actuating capabilities, by which services such as data and information are provided to the environment in which it acts whether cloud-based or local. The physical and cyber systems are designed together concurrently to maximize the efficiency of the system and this is the most important distinction in CPS [4]. The fourth industrial revolution has as its basic driving force, the application of the ability of the CPS in providing a means of inter-system communication and artificial intelligence enabling the systems to operate on a self-controlled basis for artificial, technical systems known as smart systems which are seen as a descendant of adaptogenic and mechatronic systems [5]. Applications of mechatronics as depicted in Fig. 1 are found in various fields ranging from entertainment to household devices to sophisticated equipment used in labs to the simple robot arm. Some of these applications can be found in manufacturing, transportation, smart robotics, smart home, defense, sanitation, space exploration, medical, digital cd players, personal laptops, SCADA, smart sensors, signal finetuning, and so on [6]. These applications play a major role in the fourth industrial revolution as bridges upon which it is built [7].

2. Historical perspectives on the application of mechatronics and fourth industrial revolution

2.1. Applications of mechatronics

Commonplace applications of mechatronics include:

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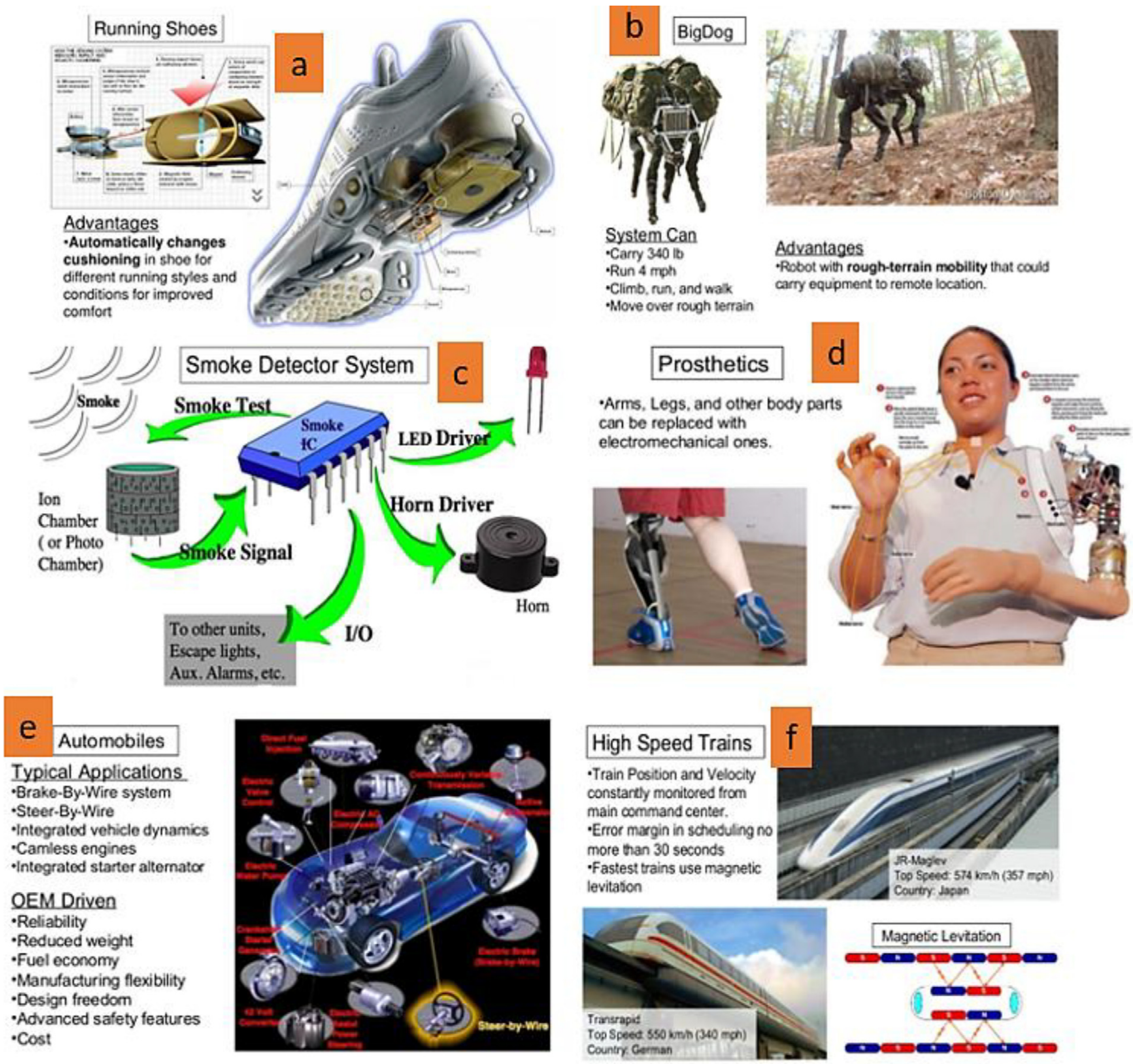

Fig. 1. Applications of Mechatronics (a) Sport (b) robotics (c) home (d) medical (e) automobiles (f) transportation.

a) **Autonomous Robots –** Currently many manufacturers have turned to the use of robots in dealing with the various complex manufacturing processes that are undergone in various industries. An increase in autonomy, flexibility, and collaboration is a main driving force in their continual use, an example is Kuka which is offering autonomous robots that interact with one another [8].

b) **Big Data and Analytics –** A lot of attention has been drawn to the explosion of data and the resultant need to develop systems to collate and analyze the data present in large volumes. The manufacturing world has seen analytics done on the large data sets it generates and it has led to production quality optimization, energy savings, and improved service of the equipment used. This is an application of mechatronics with the data drawn from sensors and manufacturing objects placed in the manufacturing process. This has been applied to creating various enterprise and customer management systems [9].

c) **The Industrial Internet of Things –** Currently, a few manufacturers have through the use of embedded computing created a network connecting the various sensors and machines. The network is typically organized such that field and sensor devices possessing limited automation and intelligence alongside their controllers feed their data into the overall coordinating manufacturing process control system in a vertical automation pyramid [10]. But with the Industrial IoT, standard technologies will be used in connecting more embedded computing enriched devices which might include even products in the development stage—. It leads to a decentralization of the analysis of data and decision making by enabling interaction and communication of field devices with one another and when necessary with more controlled centres [11].

d) **Additive Manufacturing –** Additive manufacturing technology has been recently adopted by various companies with them using various processes especially 3-D printing mostly for production and prototyping of specific specialized components especially hybrid biocomposite [12], prediction of extrusion load at different lubricating conditions [13], porcelain crowned tooth [14] and friction stir technologies [15]. In Industry 4.0, small batches of customized products made from complex, lightweight designs that offer an advantage construction-wise over traditional manufacturing methods will become ubiquitous as a result of these additive-manufacturing methods. Also, transport distances and inventory will be greatly reduced as a direct result of high performance, decentralized additive manufacturing systems [16,17].

e) **Augmented Reality –** A range of services are supported by AR-based systems, like choosing parts in a warehouse and submitting instructions on how to repair machinery over mobile devices. Such technologies are currently being developed and businesses will use the enhanced knowledge even more widely in the future to provide employees with information in real-time for improved work processes and better decision making [18]. For example, workers may be told how to repair a component while looking at the actual device to be fixed. This knowledge will be given to workers through the use of AR glasses placed directly in the line of sight of the workers.

f) **Simulation –** Products and materials of 3-D simulations with processes of production are the engineering phases that are already in use but in the future, simulations also will be more widely used in the plant operations. These simulations will leverage real-time data in a virtual model that can include machines, products, and people to reflect the physical world [19]. This helps operators in checking the setting of the machine for the next virtual product before a physical transition, thus reducing the deployment times of the machine and improving the quality [20].

g) **Vertical and Horizontal integration system –** Most IT applications are not fully implemented. Firms, manufacturers, and consumers never have close relationships. There are divisions like infrastructure, manufacturing, and operation. The organization does not completely incorporate its activities at the level of the store floor [21]. There is also a lack of full integration of engineering itself, from goods to plants to automation. Nonetheless, Industry 4.0 will offer even greater unity to businesses, teams, roles, and capacities as unified networks of data integrations grow through businesses and allow for a truly automated value chain [22].

Some have likened the fourth Industrial Revolution to Industry 4.0. It marks the latest development of automation and data sharing in manufacturing techniques, the idea of interconnection between different technologies and different devices come from the third industrial revolution. Smart factories are built and developed on modular systems of organization and logistics that allow huge amounts of production and process data to be collected. With this data, it will be possible to take not only smarter decisions to maximize and generate performance, but also a modern user-machine interface designed to reduce market time. Industry 4.0 has introduced fully integrated manufacturing where workers, computers, modules, and systems are interconnected and able to communicate and collaborate in real-time (See Fig. 2). Thanks to its organization and expertise in applying the concepts of mechatronics, Denken Italia Srl can play a leading role in the Fourth Industrial Revolution, as well as in Industry 4.0; providing complete support for automating the manufacturing cycle, building machines, and automated lines, from design to construction.

2.2. The fourth industrial revolution

In evaluating the impact of the 4th industrial revolution as presented in Fig. 3.

The Fourth Industrial Revolution (or Industry 4.0), combined with the new smart technology, is the ongoing revolution of conventional manufacturing and industrial practices. It focuses mainly on sophisticated devices mainly for machine communication and applications on the Internet of Things (IoT) to provide enhanced automation, self-monitoring, and better connections, as well as smart machines capable of analyzing and diagnosing problems without human intervention. In the 1990s, the explosion on the Internet and telecommunications industry revolutionized the way we communicated and shared knowledge. This has contributed to fundamental changes in the manufacturing sector and mainstream production processes combining physical and virtual world boundaries [41]. Technology developments often alter how humans create things. Often called the Industrial Revolution is the move into industrial technology, which was different from previous ones. Modern manufacturing techniques have radically altered people's lifestyles as well as working conditions.

The first industrial revolution involved a change from manual to machine manufacturing methods by the use of steam power and waterpower. This took a long time to introduce modern technology, and the era that this applies to is between 1760 and 1820, or 1840 in Europe and the US. In the 18th century, the First Industrial Revolution began with the introduction of steam power and manufacturing mechanization. The effects had consequences for textile production, which was to see these changes first, as well as for the iron industry, agriculture, and mining, although it also had social implications of an ever-growing middle class. At the time it even influenced the British industry [2,54]. The era between 1870 and 1914 is happened to be the span of the second industrial revolution, or best known as the technological revolution. In the 19th century, the 2nd Industrial Revolution began by discovering the development of electricity as well as an assembly line. Another significant area is in the vast railroad networks and the telegraph made it possible for people and ideas to be transmitted more easily. It is also marked by increasingly present electricity that has enabled the electrification of factories and the modern production line. This period also registered as the entrance of enormous economic growth birthed with lots of production gains. However, it triggered an increase in unemployment as many jobs in factories were replaced by machines [34,36,48]. In the late 20th century, following the conclusion of the second world War, the third industrial revolution emerged as a result of a decline in industrialization and technological development relative to previous times. Sometimes known as the modern era. It must be noted that the 1929 financial depression was one of the disruptive economic trends that have arisen from the first two revolutions in many developed countries. Z1 production happened to be the debut entranced into advanced and modern digital technologies. This followed by the next major advance in the growth of supercomputer communication technologies. Throughout this process, where the computer and communication technology were used extensively in the manufacturing process. Machines started to abolish the need for human power in life [34,36,48]. Klaus Schwab, the executive chairman of the World Economic Forum, first coined the term Fourth Industrial Revolution in a 2015 article in Foreign Affairs, "Mastering the Fourth Industrial Revolution," which was the topic of the 2016 World Economic Forum Annual Meeting in Davos-Klosters, Switzerland. The Forum declared the opening of its Fourth Industrial Revolution Centre, in San Francisco, on October 10, 2016. This was also the focus and description of the book Schwab released in 2016. In this fourth age, Schwab involves innovations that integrate biology (cyber-physical systems, software, hardware, and highlights developments in communication and connectivity. Schwab believes that this period will be characterized by breakthroughs in new technologies in fields such as quantum computing, robotics, the industrial internet of things (IIoT), nanotechnology, biotechnology, artificial intelligence, unified consensus, 3D printing, the internet of things, fifth-generation wireless technologies (5 G), as well as fully autonomous vehicles [3,53].

Fig. 2. Interconnectivity of different devices with Industry 4.0.

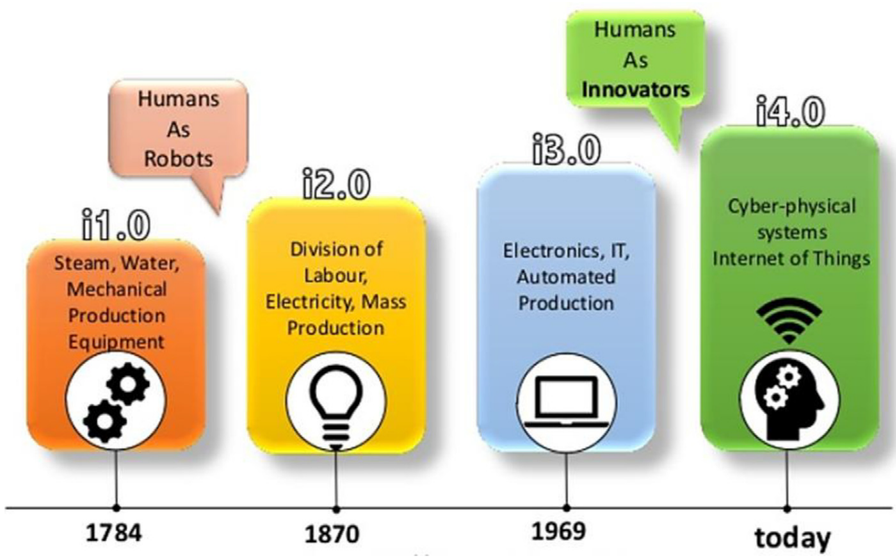

Fig. 3. The Evolution of Industry 4.0.

2.3. Fundamental factors that make fourth industrial revolution

Industry 4.0 improves goods and production processes such as equipment, warehouses, and operational services by turning them to a CPS and is connected with global manufacturing networks [23]. Such smart entities can interact, analyze available data, execute actions, and together have the power to autonomously monitor and optimize themselves [24]. Smart goods are clearly identified, always know their respective past and alternative ways of completing production. Intelligent produce systems are always connected to most of the company processes, systems, and the manufacturing network's whole value chain. This makes it possible to track the supply chain in real-time and optimize for final delivery [25]. The integration between the digital and physical world and CPS enables the modern autonomous and decentralized manufacturing model [26]. Based on technology, four fundamental factors make up the fourth industrial revolution according to [27], these are:

- Cyber-physical systems
- Internet technology (IoT, IoS, IoD)
- The components as carriers of information and
- Holistic safety and security including privacy and knowledge protection *etching*

2.3.1. Cyber-physical systems

CPS has been defined as an intersection of computation theory and that of dynamic systems [14], this has resulted in two complementary approaches which are

- Cyberizing the physical: these targets deriving computational interfaces and abstractions from specified physical subsystems, taking various physical subsystems, and building virtual replicas. This is achieved by equipping the various physical systems with intelligence through the use of embedded systems. With communication between other CPS as well as humans being of paramount importance [28].
- Physicalizing the cyber: this refers to expressing the dynamic behaviour of dynamic systems and network components in software and interfaces [29]. Cyber-Physical Systems can be understood to be a culmination of increase in complexity from embedded systems to smart sensors to smart systems consist-

ing of smart sensors and actuators to the addition of network access to the smart systems creating the CPS which on combination with other CPS and appropriate manufacturing objects become the Cyber-Physical Production Systems [30].

2.3.2. Internet technology

The performance of CPSs is improved by applying modern and future internet technology. These internet technology approaches comprise 3 concepts [31]

- *The Internet of Things (IoT):* This consists of communicating - smart systems using IP-addresses. The upcoming IPv6 (internet protocol version 6) supports an IP address space of 128 bits which enables us to define 2^128 individual addresses or $3.4 * 10^{38}$ addresses [32]. This enables equipment of every physical object with a unique IP-address providing for detection, identification, and location of physical objects connected by the IoT no matter how numerous they are [33].
- *The Internet of services (IoS):* It involved new services-paradigms such as types of service provided by oriented architecture (SOA) [11] or the REST-technology [33]. This introduces concepts for providing services specific to products on-demand as well as the provision of knowledge about product behaviour controlling services. It also boosts the interactions between machines, peoples, and systems thereby improving the value of the CPSs [1].
- *The internet of data (IoD):* In an environment of the previously mentioned internet of things and the internet of services technologies a huge amount of data will be generated. The internet of data will enable to transfer and to store mass data that appropriately and to provide new with innovative analysis methods to interpret mass data in the context of the target application [34].

2.3.3. Components as information carriers

The approach of cyber-physical systems enables objects to be identified, localized and addressed. Assigned to manufacturing objects such as single parts and assemblies this technology opens new innovation paths [35]. Manufacturing objects become information carriers as well as connected objects in a network of communicating instances. Manufacturing history assigned to manufacturing objects creates individual object information which is essential for successive manufacturing processes and backtracing analysis [36].

Furthermore, manufacturing objects are connected to product model structures as well as process planning data and thus, they are enabled to actively control their manufacturing processes and procedures [37].

2.3.4. Holistic safety and security including privacy and knowledge protection

Cyber-physical systems equipped with internet technology (IoT, IoS, and IoD) require outstanding concepts and technologies to ensure safety, security, privacy, and knowledge protection. These concepts have to be applied in a real-time environment that typically addresses manufacturing environments [38].

Safety requirements address the continuously available manufacturing operation ability while security aims at the resilience against external and internal attacks against the cyber-physical environment [39].

Privacy ensures the execution of operational functions without being monitored to a third instance. Furthermore, knowledge protection provides methods and tools to avoid access to manufacturing knowledge from outside or non-authorized instances [40]. Industry 4.0 concepts require IT safety and security to be tied closely to physical manufacturing processes also meeting real-time requirements.

2.4. Impact of fourth industrial revolution

The relationship between manufacturing processes and Industry 4.0 is presented in Fig. 4. This clearly defined the role of the 4th industrial revolution in manufacturing. This played a huge impact on the 4th industrial revolution.

2.4.1. Revenue growth

Besides, Industry 4.0 would fuel growth in sales. Demand for increased machines and new data applications from manufacturers and demand from consumers of an ever-increasing variety of goods would raise additional revenue of €30 billion per year [42].

2.4.2. Employment

It was also found that the growth it generates will lead to a 6% rise in jobs over the next ten years over our study of the effects of Industry 4.0. And the demand for mechanical engineering employees can also increase by up to 10% over the same period. Nonetheless, it may take specific skills [43]. Throughout the short term, the movement towards increased automation will change the way people are employed with some mostly poorly qualified employees that perform some basic tasks being forced to give way [44]. Around the same period, the rising use of apps, networking, and analytics will fuel the demand for workers with expertise in information and IT technology development. This transfer of expertise is the most important challenge [45].

2.4.3. Investment

The adaptation to industrial incorporation of industry 4.0 will require German manufacturers to invest approximately €250 billion (around 1–1,5%) in the next ten years [46].

2.5. The role of applications of mechatronics in the fourth industrial revolution

2.5.1. Big data and analytics

This provides factories with the ability to process data generated from the IoT created by interconnecting various CPSs in a factory [47], analyze them and enable the autonomous system to make decisions on how to proceed with the manufacturing operation. It also enables a vertical integration of production systems thereby making the existence of interacting CPSs possible [48].

2.5.2. Industrial internet of things

The Industrial Internet of Things enables the enrichment of a multitude of devices—oftentimes including even uncompleted products—with embedded computing and creating a connection between them using standard technologies [49]. The IoT thus makes communication between field servers as well as with centralized controllers as necessary thus decentralizing analytics and decision making and making real-time responses possible. It also makes vertical integration possible by providing the link between CPSs [50].

2.5.3. Augmented reality

Augmented Reality (AR) will play a major role in changing how humans and machines relate providing workers with the ability to have more information available to them as well as enabling work to be done remotely in real-time [51]. It is currently applied in the automobile sector where it is deployed in AR glasses which highlights the location where each part is to be mounted during the manufacturing process, reducing error and increasing accuracy [52].

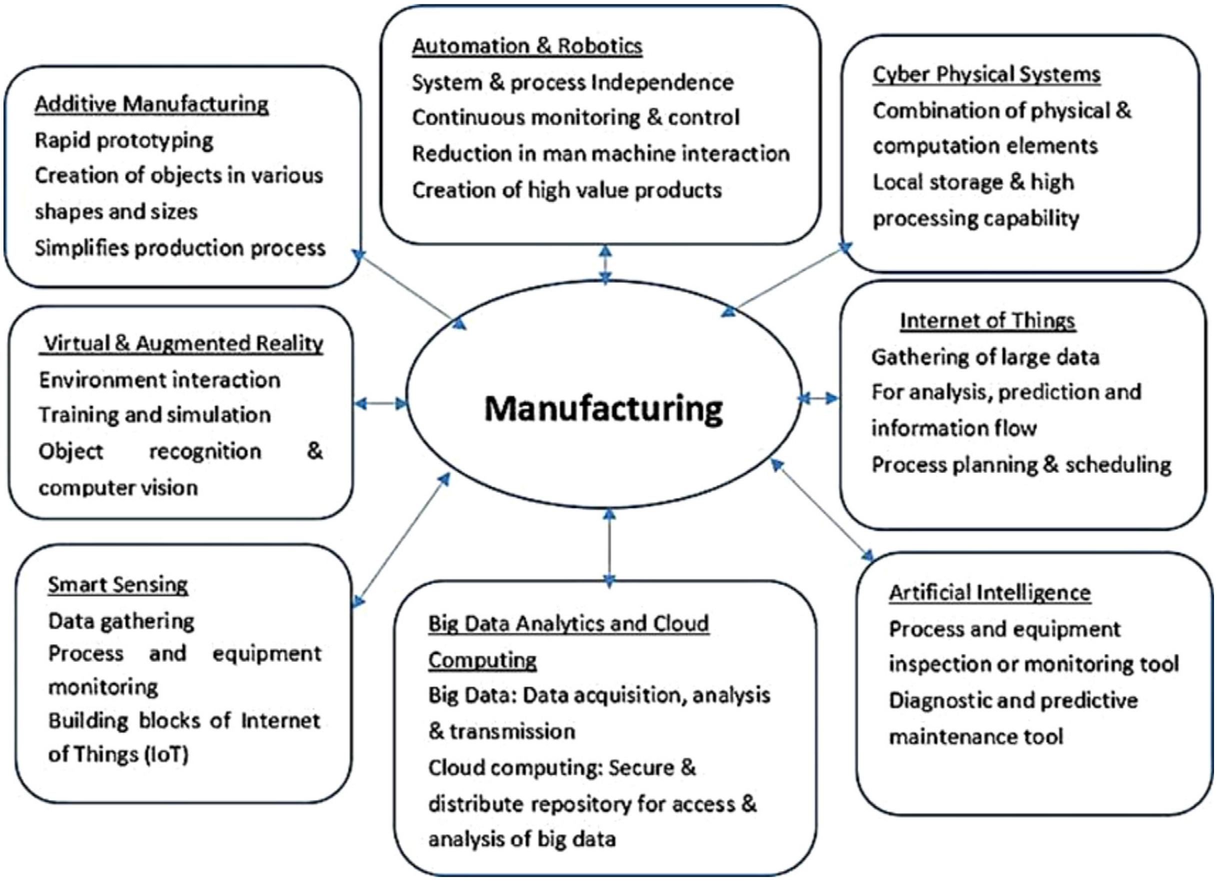

Fig. 4. Relationship between manufacturing processes and Industry 4.0.

2.5.4. Autonomous robots

Under industry 4.0, work in the factory is going to be done mostly by autonomous robots connected by the IoT into CPSs which are all integrated enabling the robots to continuously produce high-quality products without human intervention while learning from mistakes made [39].

3. Conclusions

The fourth industrial revolution is the next big step in the evolution of industries, and it will result in Smart self-controlling production systems. Mechatronics is a broad field of knowledge combining elements of mechanical, electronic, and information technology. Applications of mechatronics play a major role in this revolution by providing the basis for communication (IoT), processing information (Big data and analytics), actuating (Autonomous robots), and Human-machine interactions.

In sum up, industry 4.0 is about linking the worlds of physics and digitality. Many of the essential properties of the producer today are a part of the physical environment. The staff, tools, equipment, and inventories driving both the manufacturing process and the final product that consumers use every day. Nevertheless, emerging technologies enable manufacturers to use the data generated by these physical assets to drive data-based insights. The fourth industrial revolution has arrived there, especially towards "Smart Manufacturing."

CRediT authorship contribution statement

Sunday A. Afolalu: Conceptualization, Investigation, Methodology, Writing - original draft, Funding acquisition. **Omolayo M. Ikumapayi:** Writing - review & editing, Project administration, Resources. **Ademola Abdulkareem:** Writing - review & editing. **Samuel B. Soetan:** Writing - review & editing. **Moses E. Emetere:** Writing - review & editing, Funding acquisition. **Samson O. Ongbali:** Supervision, Visualization, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further Reading

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