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Who should manage production in modern manufacturing? The product, the manufacturing system, or the factory

¿Quién debe dirigir la producción en la manufactura moderna? El producto, el sistema de manufactura o la fábrica

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Resumen

Actualmente, los sistemas de producción han evolucionado con la llegada de nuevas tecnologías y paradigmas de manufactura, siendo dependientes en la evolución e implementación de los sistemas ciber-físicos (CPS) que representan la tecnología clave para implementar los complejos requisitos de la manufactura moderna. Los CPS pueden ser divididos en una entidad con sus correspondientes escenarios. La entidad integra toda la información referente al objeto físico o sistema, mientras que los escenarios representan todo el contexto en el que la entidad está involucrada, incluyendo información estática y dinámica. La información estática incluye datos como la estructura del equipo y ubicación geográfica mientras la información dinámica involucra datos sobre el medio ambiente, el consumo de energía, la operación, entre otra. Por lo tanto, la correcta aplicación de cualquier CPS debe estar enfocada en sus respectivos escenarios como la gestión de la producción a través de la fábrica, o el control de las etapas de producción a través del producto. El pleno potencial de cualquier CPS solo se puede alcanzar mediante la integración de la entidad y sus correspondientes escenarios. Esta investigación presenta un análisis sobre los CPS y los paradigmas de manufactura más recientes, así como un análisis sobre los escenarios del control de la producción desde la perspectiva de los principales tipos de CPS involucrados en la manufactura, descritos utilizando el modelo en cinco dimensiones (objeto físico, contraparte virtual, conexiones, datos y servicios) propuesto por Grieves. Estos CPS son las fábricas inteligentes, productos inteligentes y sistemas de producción ciber-físicos, que, si bien comparten las bases de los CPS en general, también presentan diferencias en sus actividades y escenarios según su función, estructura, contexto y entorno. Pero al ser dispositivos inteligentes con capacidad de razonar y actuar, tienen la capacidad para dirigir la producción de forma autónoma.

Palabras clave: manufactura inteligente, sistemas ciber-físicos, sistemas de producción ciber-físicos, sistemas inteligentes de manufactura, productos inteligentes, fábricas inteligentes.

Abstract

Today, manufacturing systems have evolved with the arrival of new technologies and production paradigms, depending on the implementation and evolution of cyber-physical systems (CPS), that represent the key technology to implement the modern complex requirements of manufacturing. CPS can be divided into an entity and its corresponding scenarios. The entity integrates all the information regarding the physical object or system, while the scenarios represent the entire context in which the entity is involved, including static and dynamic information. Static information includes data such as equipment structure and geographic location, while dynamic information involves data about the environment, energy consumption, operation, among others. Therefore, the correct application of any CPS must be focused on its respective scenarios such as the control of production through the factory, or the control of production stages through the product. The full potential for any CPS can only be achieved by the integration between the entity and its corresponding scenarios. This research presents an analysis about CPS and the most recent manufacturing paradigms, as well as an analysis about the production control scenarios from the perspective of the main types of CPS involved in manufacturing, described using the five-dimensional model (physical object, virtual counterpart, connection, data, and services) proposed by Grieves. These CPSs are smart factories, smart products, and cyber-physical production systems, which, while sharing the basics of CPSs in general, also present differences in their activities and scenarios according to their function, structure, context, and environment. But being intelligent devices with the ability to reason and act, they have the capability to manage production autonomously.

Keywords: Smart manufacturing, cyber-physical systems, cyber-physical production systems, intelligent manufacturing systems, smart products, smart factories.

1. Introduction

Nowadays, products and manufacturing systems are becoming increasingly complex, allowing customized requirements to be met and even unique items to be produced profitably, with the ability to respond positively to interruptions and failures of any kind. [19].

Industrial areas are experiencing a fourth industrial revolution, a momentous change based on digitization that affects all business activity inside and outside an enterprise. And as already happened with past industrial revolutions, new business processes need be developed in conjunction with new technologies to remain competitive [10].

Due to the arrival of new manufacturing paradigms in complex industrial ecosystems, such as ubiquitous manufacturing [11], cloud manufacturing [10] or smart manufacturing [21], there is a need to adopt new architectures [1] and business processes that help organizations with the adaptation and evolution of existing architectures and technologies towards the new manufacturing paradigms [42]. Additionally, engineers must redesign processes, factories, and operations to accommodate these new advances into increasingly smart manufacturing facilities [13].

The design of manufacturing systems is considered a complex problem [15] and modern industry requires that the next generation of manufacturing systems to be smart, flexible, and interoperable, capable of delivering better performance at lower cost [37]. Current data analysis techniques [41] and artificial intelligence [23] play an essential role in future production systems by providing features such as the ability to learn, reason and act [40]. Artificial intelligence will allow manufacturing systems to learn from experiences to finally realize a connected, intelligent, and ubiquitous industry [44].

In addition, cyber-physical systems (CPSs) have become the fundamental technology of new production paradigms. CPSs are defined as the combination of the physical and digital worlds, allowing both worlds to be connected and act as one. Everything that happens on the physical world impacts on the virtual world and vice versa [20 CPSs are considered autonomous and intelligent systems with the ability to exchange information, trigger actions and control each other, developing an open and smart manufacturing environment [38]. CPSs possess a virtual model that is a replica of their corresponding physical entity and can simulate the characteristics, behavior, wear and tear and performance of its physical counterpart. CPSs may be modeled using the five-dimension framework postulated by Greaves that comprises the physical object, virtual counterpart, connection, data, and services [32].

Additionally, any CPS can be divided into its entity and its corresponding scenarios. The entity integrates all the information regarding the physical object or system from a ubiquitous perspective, while the scenarios represent the entire context in which the physical entity is involved, including static and dynamic information. Static information includes data such as equipment structure and geographical location, and dynamic information involves data about the environment, energy consumption, operation, among others [26]. Therefore, CPS applications must focus on scenarios, for example, to achieve the ideal conditions in a process or to achieve specific functions in a machinery. Some more complete and complex scenarios are represented by the control of the production through the smart factory or by the control of production stages through a smart product. The full potential in any CPS can only be achieved by the integration between the entity and its corresponding scenarios.

Finally, the physical world for a CPS may consist of device, product, process, system and even an organization, whose hierarchy can be divided into three levels, where each one implements its activities according to its physical laws, functions, structure, and uncertainty within their respective environment. These levels are unit, system, and system of systems. Fig. 1 shows the different hierarchical levels for the CPSs involved in the manufacturing system according to their function and structure until reaching the smart factory.

For these reasons, the contribution of this paper is to perform an analysis about production control scenarios from the perspective of the main types of CPSs involved in manufacturing and described using the five-dimensional framework proposed by Grieves. These scenarios are smart factory-driven production, smart product-driven production, and CPPS-driven production. These main types of CPSs share the bases of CPSs in general, but also present differences in their activities and scenarios according to their function, structure, context, and environment. But being intelligent devices with the ability to reason and act, they have the capability to direct production autonomously. It should be highlighted, although today there are studies that analyze the new manufacturing paradigms such as Chen & Tsai [11], Kusiak [21], Zhong et al. [44], Charro & Schaefer [10] and even CPSs [18,26,31], there are no papers describing the production control scenarios from the perspective of these main types of CPSs involved in the manufacturing workshops.

The rest of this paper is organized in the following way. In Section 2 are presented the new manufacturing paradigms. Section 3 discusses about cyber-physical systems in detail. Section 4 analyzes the production control scenarios from the perspective of the main types of CPSs involved in manufacturing. Section 5 shows the discussion. Section 6 presents the conclusions and future work.

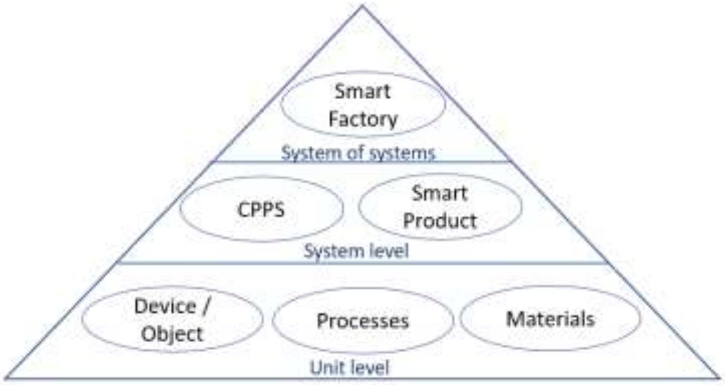

Figure 1. Hierarchical levels for the different types of CPSs according to function and structure up to the smart factory.

2. Manufacturing paradigms in the fourth industrial revolution

With the arrival of the fourth industrial revolution and recent technological advances, new manufacturing paradigms have emerged to increase efficiency and productivity on the workshop floor and to satisfy complex markets. Among these new paradigms, the most important and outstanding are cloud manufacturing (CM), ubiquitous manufacturing (UM), and smart manufacturing (SM). The extension of the cloud computing applied to manufacturing has generated the concept of CM, recognized as one of the most fundamental and innovative technologies for the modern industry, demanding increasingly attention into the manufacturing area [9]. The CM term has been proposed to adopt cloud technologies in manufacturing, improving the current production systems [37].

UM is an application of cloud computing in manufacturing, which refers to the ability to design, make and sell anywhere, and at any time. This paradigm provides factories with unlimited production capacity and permanent availability of manufacturing services [11].

Finally, SM represents the tomorrow´s production, causing a rapid increase in the volume of publications on this topic [21]. SM is not only concerned about the automation of production workshops but uses data-driven innovations to achieve high levels of autonomy and optimization in business processes [43]. The following subsections discuss these novel paradigms in detail.

2.1 Cloud manufacturing

The term cloud manufacturing (CM) was first introduced in 2010 like a model to allow convenient, ubiquitous and on-demand access to virtualized, encapsulated, and configurable manufacturing resources, for example, manufacturing tools, equipment and services. Also, it can be described as a holistic cloud-based design and manufacturing vision to achieve the entire production process as a whole [4,10]. CM can change how production services are given, providing to the user ubiquitous access through cloud computing to CPPS, smart machines and big data generated on production floors [9].

CM, developed on the top of cloud computing, is fundamental to achieve the vision of SM in the context of the fourth industrial revolution. CM also uses a share-to-gain thinking and allows the connection between dispersed production resources and facilities [10].

The ASME (American Society of Mechanical Engineers) has pointed out that cloud providers can support manufacturing applications with more cost-effective and scalable access, for example, cloud-based CAD systems will be available soon and Autodesk already provides cloud-based applications for collaborative design [37].

2.2 Ubiquitous manufacturing

In 1988, Mark Weiser introduced the idea of ubiquitous computing (UC) by predicting that UC models would become widely used. In 1999, IBM formally proposed the term. One of the most significant goals of UC is to allow computer equipment perceive changes in the surrounding environment and modify their behavior according to these changes. UC enables people access to the information without restrictions of time or place, providing the most effective way to perceive the location of individuals or objects, environmental information, personal situations, and tasks [33]. Ubiquitous Manufacturing (UM) refers to the ability to design, make and sell anywhere, and at any time. This paradigm provides factories with unlimited production capacity and permanent availability of manufacturing services. UM is similar to CM but UM emphasizes the mobility and dispersion of users and resources. CM typically deploys cloud services through the Internet, whereas UM does not need a network. For instance, Kinect, that is very frequently used in UM, does not need network access to work. However, CM and UM benefit from each other, for instance, the device status monitored using a ubiquitous sensor can be inspected using a service deployed in the cloud. Finally, one of the main challenges for UM is the lack of organizational methods (including mediation and negotiation services) and adequate communication infrastructure [11].

2.3 Smart manufacturing

Due to the enormous complexity of modern manufacturing systems and the increase in the volume of data, decision-making is increasingly complex, emerging the need to use computational intelligence to take the best decision in the right place and time [11].

In SM, typical manufacturing resources are converted into smart objects that can act, behave and sense into a smart environment [44]. The environment into a smart factory consists of a new communication and real-time integration of all manufacturing resources (sensors, actuators, conveyors, machines, robots, among others). This integration allows to increase manufacturing efficiency and meet the requirements of complex markets [24].

According to the National Institute of Standards and Technology (NIST), SM is a collaborative real-time production system that satisfies changes in customer needs or in the conditions and demand for the factory. SM joins together production resources with cloud computing, communication tools, big data, simulation, and artificial intelligence. Also applies concepts like CPSs, IoT, service-oriented architectures, and data science [21].

SM uses information and communication technologies into manufacturing to achieve flexible and reconfigurable processes to optimize production, quality, service level and being able to face global and dynamic markets. With SM, all information and physical processes are available where and when are needed [36,44]. The intelligence level in the company will be determined by the degree in which the physical assets have been reflected in the virtual world, in addition to the amount of manufacturing processes information is available in the right place, time and form. SM prioritizes the autonomy, evolution, simulation, and optimization, and not only the degree of automation on the manufacturing workshops [43].

SM also improves the design, production, management, and products life cycles by using advanced sensors, smart objects, smart materials, and decision-making models based on data analysis. Simultaneously, SM systems will be able to give personalized, collaborative, and robust services to users. Artificial intelligence techniques will play an essential role in these systems by providing features such as the ability to learn, reason and act. Artificial intelligence will minimize the variability caused by people within manufacturing systems and processes, while addressing SM challenges. These challenges include the development of smart manufacturing systems, data-driven SM models, deep integration and collaboration between people and machines and development of real application cases [44].

3. Cyber-Physical Systems

CPSs are the fundamental technology into the new manufacturing paradigms. CPSs are autonomous systems that allow the connection between operations and processes through information and communication technologies (ICT). As shown in Fig. 2, a CPS is composed of a control unit, generally one or more microcontrollers that control the sensors and actuators required to interact with the real world and process the data [18].

CPSs applications exist in many areas such as manufacturing, robotics, smart grids, among others [31]. By using CPSs, the intelligence is not centralized but distributed throughout processes, giving at the same time, greater stability, and flexibility to operations [20]. Companies are trying to set networks that integrate devices, machines, big data, and production environment, all into CPSs [19].

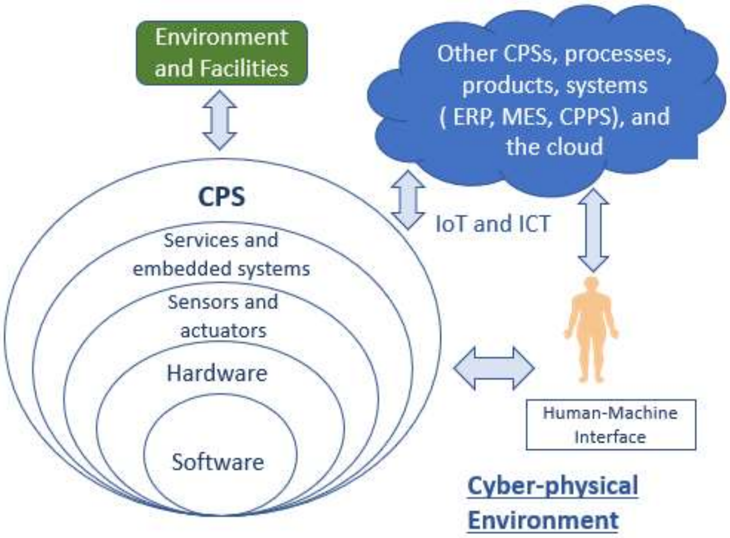

Figure 2. The Cyber-Physical Environment.

CPSs can be modeled in 5 dimensions: the physical entities, virtual model, services, data, and connections. The virtual model reflects the physical phenomena of the entities such as deformations, fractures, corrosion, also reproduce the physical geometries, properties, behaviors, and rules. Behavior model describes the state, performance degradation, coordination, transitions, and responding process to changes in the environment. Rules provide to CPSs abilities to reason, evaluate, and take intelligent decisions [26]. The services are essential components in the CPSs that provide users with applications concerning prediction, simulation, verification, virtual experimentation, optimization, and virtual education, including intelligent diagnostic and maintenance for monitoring, and managing the health in assets and processes [22]. The services transform the factory in robust and reliable, increase efficiency and productivity, reduce production costs, improve process performance while decreasing defects [9].

CPSs own a decentralized control and advanced connectivity that allow the collection and exchange of information in real time to identify, locate, track, monitor and optimize the corresponding process or resource, using autonomous decisions based on machine learning algorithms and data recorded previously [29]. CPSs include architectures that require communication interfaces to exchange data with enterprise and operational systems, clouds, and human resources. Data exchange is the most important feature in CPSs, since data can be related and evaluated [18]. This model involves real machines operating with cloud platforms that simulate conditions and integrate knowledge based on deep learning algorithms driven by data, as well as another available physical knowledge [17].

Unlike traditional embedded systems, which are designed as independent devices, the focus on CPSs is in creating networks integrated by various devices. CPSs allow you to have the information and services available everywhere and anywhere. This implies that it is possible to control the CPSs remotely [18]. In addition, CPSs allow communication among humans, machines, and products [8,14]. Therefore, CPSs are collaborative computational systems that are in intensive connection with the physical surrounding world and their ongoing processes. Through CPSs, the physical and software components are deeply connected, representing a higher level of integration and coordination between the physical and computational elements, while devices will be able to colaborate with other resources and decentralized control systems will optimize the production [42].

The integration of CPSs with production, logistics and services will carry out an industrial transformation translated into cyber-physical production systems (CPPS). CPPS applied to production, allow connection at all levels, including autonomous and cooperative elements (smart machines) with subsystems and smart factories [15]. The application of CPSs in manufacturing will carry out a vertical and horizontal integration of information systems and the entire supply chain interconnection [34].

A priority into the design and development of CPSs is always to know their status. This status not only includes whether a CPS is busy or not, but also being informed about health, wear and tear and if it is working properly. This information is very important to determine if it is possible to assign certain tasks and distribute to each CPS accordingly [43].

4. Production control scenarios

Any CPS can be divided into its entity and its corresponding scenarios. The entity integrates all the information regarding the physical object or system from a ubiquitous perspective, while the scenarios represent the entire context in which the physical entity is involved, including static and dynamic information. Static information includes data such as equipment structure and geographic location, and dynamic information involves data about the environment, energy consumption, operation, among others [26]. Therefore, any CPS application must be focused on scenarios, for example, to achieve the ideal conditions in some process or to achieve specific functions in a machinery. Some more complete and complex scenarios are represented by the control of the production through the factory, or by the control of production stages through the product. The full potential in any CPS can only be achieved by the integration between the entity and its corresponding scenarios.

Finally, the physical world for a CPS may consist of device, product, process, system and even an organization, whose hierarchy can be divided into three levels, where each one implements its activities according to its physical laws, functions, structure, and uncertainty into their environment. These levels are unit, system, and system of systems. The following sections discuss and make an analysis about the production control scenarios from the perspective of the main types of CPSs involved in manufacturing and described using the five-dimensional framework proposed by Grieves. These CPSs are smart factories, smart products and CPPS, although they share the bases of CPSs in general, also present differences in their activities and scenarios according to their function, structure, context and environment. But being intelligent devices with the ability to reason and act, they have the capability to direct production autonomously.

4.1 Smart product-driven production scenario

One of the main objectives in modern manufacturing is to satisfy individual customer requirements, affecting areas such as order management, research, and development [35]. With the fourth industrial revolution, a new purchase method is being provided to customers, allowing them to order any feature that can be included into the products, it means they are oriented to customization [27].

4.1.1 Physical part

The change from clients buying products towards clients demanding benefits and solutions is a priority in modern manufacturing and can be resolved as the development of different levels of servitisation. Where servitisation means the process of creating value by adding services to tangible products [39].

In smart products, the development from product-service systems or services through the product is seen as a key strategy. The tangible product includes just the core product bought by the client. In smart products, the development of product-service systems is a key strategy. The tangible product includes just the core product bought by the client. This is the first level of servitisation, the difference with other competitors is obtained through the functionality, price and quality. Product and service scenarios comprise the functionality of the core product supported by services. These services can be obtained alongside the original product and give new functions to the client (charged for separately). Personalized features are increasingly viewed as a competitive advantage. Product-to-service scenarios decouple the production of goods and the sale of services. The client buys services that are grouped to solve a particular problem or need. The original product will probably not be sold but only used to arrive to the services. In this case, product and service development is integrated [39]. These smart products must be built with sensors that collect real-time data used to report the location, product status, and environmental conditions [29].

4.1.2 Virtual counterpart

Smart products enable the integration of physical and digital processes. Smart products are defined as products with the ability to perform calculations, store data, communicate and interact with their environment, providing data about their identity, properties, states, and history during their life cycle (see Fig. 3) [28]. Smart products must be uniquely identifiable, can always be located during the manufacturing and delivery processes, know their history, status, details about manufacturing steps, and alternative routes to reach their target status. This means that smart products can control the stages of their production autonomously [27].

Smart products have a holistic view that includes previous process steps and can define future steps. These steps not only include production phases on an unfinished product, but also future maintenance operations and even the definition of their logistics and delivery route [28]. In this way, the smart product requests the necessary resources and orchestrates the production processes until its completion [38]. In addition, the finished products know the parameters where they work optimally and recognize signs of wear throughout their life cycle. This information allows optimizing the production, logistics, execution, and maintenance, as well as the integration with management applications [19].

4.1.3 Data

Smart products use built-in sensors to collect real-time data used to report the location, status, and environmental conditions [29]. They must be also uniquely identifiable and located during the manufacturing and delivery processes, keeping data about their identity, location, history, status, details about their manufacturing process, and alternative routes to reach their target status. Through this data in addition to smart services and optimized decisions, the smart products are going to be able to control the stages of their production autonomously [27].

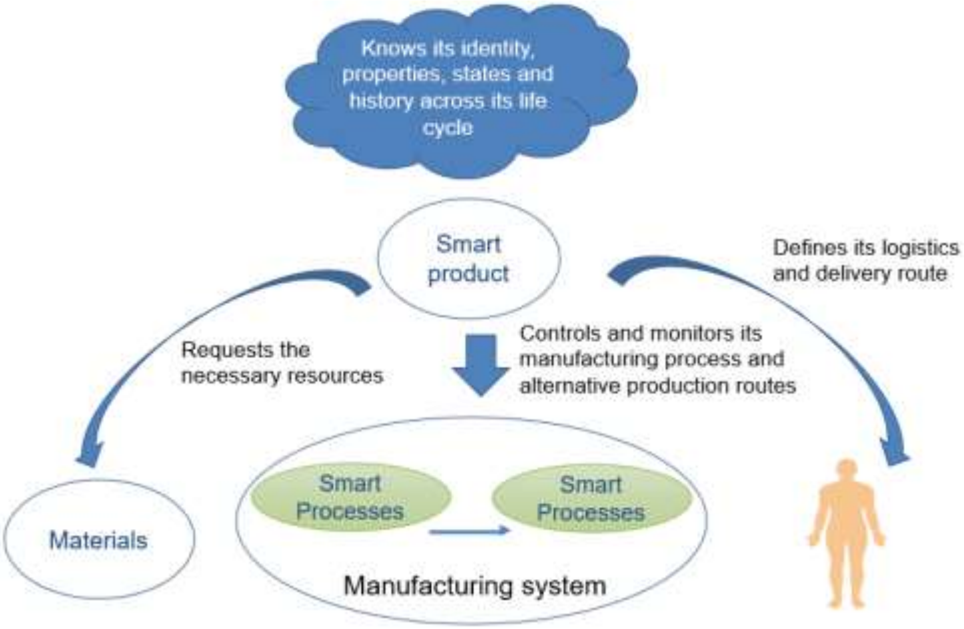

Figure 3. Production directed by the smart product.

4.1.4 Connections

Smart products are a type of CPS due to their ability to enable connection between the physical and digital worlds. These products must include connections that allow them to be integrated in real time into the value chain as an active part of enterprise and operational systems. They must also be sensitive to their environment, monitor their production processes and phases, and have the ability to request the necessary resources for their completion [24]. Through smart products, companies are generating greater value through the collaboration of these products with digital ecosystems (in different companies if it is necessary) and services [25].

4.1.5 Services

Smart products must include services to know previous and future steps and set alternative routes if it is necessary. These steps not only include production phases on an unfinished product, but also future maintenance operations. They should also include services to set their logistics and delivery route [28]. Additionally, smart products include services to request the necessary resources, and services to orchestrate the production processes until completion [38]. Through these services, the smart products will control their own production autonomously [27]. Finally, the finished products must contain a set of services to optimize the parameters where they function optimally and to recognize signs of wear throughout their life cycle. These services allow optimizing production in terms of logistics, execution, and maintenance [19].

4.2 CPPS-driven production scenario

Manufacturing systems are increasingly complex and modern industry requires that the next generation of these systems to be smart, flexible, and interoperable, capable of delivering better performance at lower cost [37]. Meanwhile current data analysis techniques [41] and artificial intelligence [23] play an essential role in future production systems by providing features such as the ability to learn, reason and act [40]. Artificial intelligence will allow manufacturing systems to learn from experiences to finally realize a connected, intelligent, and ubiquitous industry [44]. The integration of CPSs in manufacturing will carry out an industrial transformation translated into CPPS. CPPS applied to production will play a key role, since these systems allow connection at all levels, including autonomous and cooperative elements (smart machines) with subsystems and smart factories [15].

4.2.1 Physical part

CPPS consist of a set of processes implemented using modular CPSs, configured with helper functions and integrated synergistically through the infrastructure. CPPS achieve better integration between real manufacturing processes and those virtually planned [19].

4.2.2 Virtual counterpart

The control of production through intelligent, describable, manageable, and sensitive to the context manufacturing systems is a priority in the current investigations. Today, these intelligent systems evolve in the form of CPPS. CPPS know their status, capacity, different configuration options, preparation and maintenance plan and can make decisions autonomously [2]. But the business processes in manufacturing are often still static and implemented through extremely rigid and inflexible software systems. Therefore, CPPS-driven production will require a software layer that implements certain design principles such as scalability, data driven, robustness, diversity in source management (such as different sensors) and end devices, real-time data management [3] and flexibility provided by the orchestration and integration of data, applications, services and other CPSs. However, these legacy systems cannot be simply replaced by smart and ubiquitous systems. It will be essential to integrate new systems and technologies with existing ones, and legacy systems will need to be upgraded to systems with these characteristics [19].

4.2.3 Data

CPPS know their status, capacity, different configuration options, preparation, and maintenance plan to make decisions autonomously [2]. CPPS also retain information about the processes that shape it, encapsulate their own sequence of operations, location, structure, energy consumption, parameters, time metrics and resources [30].

4.2.4 Connections

The main difference between CPPS and traditional manufacturing systems is the ability to communicate, interact and collaborate with manufacturing processes, factories, and the environment [16]. CPPS enable a new real-time integration of all manufacturing resources and processes, developing a holistic vision that allows increasing efficiency, meet complex market requirements, and equip the factory with decentralized intelligence [24]. These new systems must be vertically integrated with production and business processes (see Fig. 4) [7], and horizontally with dispersed and decentralized value chains [24]. Therefore, integration is essential in CPPS-driven production, where horizontal integration means the collaboration of various software systems utilized throughout the production process, involving supply of materials, energy and data management both within an enterprise or among different enterprises. Vertical integration means the integration of software systems at the various hierarchical levels (for instance, sensors, actuators, control, production management, and enterprise planning levels) in order to achive an integral solution [19]. End-to-end integration is the most active area in the modern manufacturing. Firstly, on the production floors, integration of machines is given so that devices and machines are an integral part of the production system. Secondly, it is necessary to integrate clients into the production system, allowing researchers to get feedback from clients easily. Finally, product-to-service integration is feasible, granting that the producer directly monitor the condition of the product in use. In this way, the value network will be extended up to the customer service of the product [12].

4.2.5 Services

CPPS built with value-added services that conduct analysis and make optimized decisions will transform the production into smart, collaborative, personalized and data-driven manufacturing [44], equipping the factory with decentralized intelligence. CPPS must possess services that enable the collaboration and vertical integration with production and business processes [7], and services that enable horizontal integration with dispersed and decentralized value chains [24]. CPPS will also require services to integrate clients into the manufacturing system, thus allowing engineers and producers to obtain feedback from customers, in addition to services to monitor the condition of the product. This will achieve the product-to-service integration. In this way, the value network will be extended up to the customer service [12]. Finally, a priority in the design of CPPS is the development of services to know the status that not only includes whether a CPS is busy or not, but also information about health, performance degradation, and wear and tear.

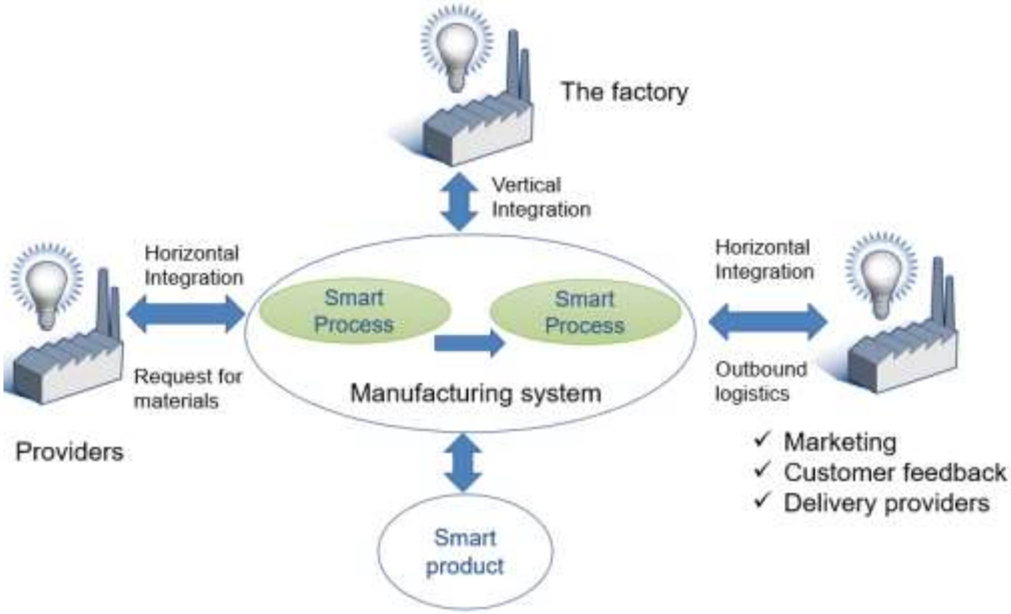

Figure 4. Production directed by CPPS.

4.3 Smart factory-driven production scenario

Manufacturing is moving towards what is known as "the smart factory", conceived as a system of systems that allows information about manufacturing processes to be available when, where and in the way, it is needed within supply chains and product life cycles performed by up to multiple industries [43].

4.3.1 Physical part

Manufacturing is moving towards the smart factory, also known as, factory of the future, ubiquitous factory, among other names. It consists of the integration, digitization, and use of flexible and smart processes across the entire value chain [28]. Smart factories have a modular structure, whose processes are controlled and monitored by CPSs that allow smart and decentralized decisions [24]. The smart factory includes all the main structures, materials, human resources, processes, systems, and other real and virtual resources of the factory in conjunction with the product [15].

4.3.2 Virtual counterpart

The smart factory aware of its own context and environment must be able to assist people, machines, and processes in the execution of their tasks. This is achieved through the integration of systems that, aware of their environment, take into account information from the context, such as the position and status of the different elements involved in the manufacturing processes, together with information from the physical and virtual world to fulfill their tasks [16]. The smart factory virtual model encapsulates and manages aspects such as complexity, inventory levels, materials, logistics, quality control, and the transportation and delivery of finished products (see Fig. 5) [30]. In this way, the factory will manufacture products more efficiently and be less prone to breakdowns [19].

The smart factory virtual model must have a holistic vision that allows the evaluation and continuous improvement of all the main structures, materials, human resources, processes, systems, and other real and virtual resources of the factory in conjunction with the product [15].

Finally, the smart factory makes it possible to produce any batch size, even individual customer requirements can be met, which means that unique and customized items can be manufactured profitably. In this way, it is possible for businesses and processes to allow last minute changes or respond flexibly to changes, interruptions and failures coming from machines and suppliers [19].

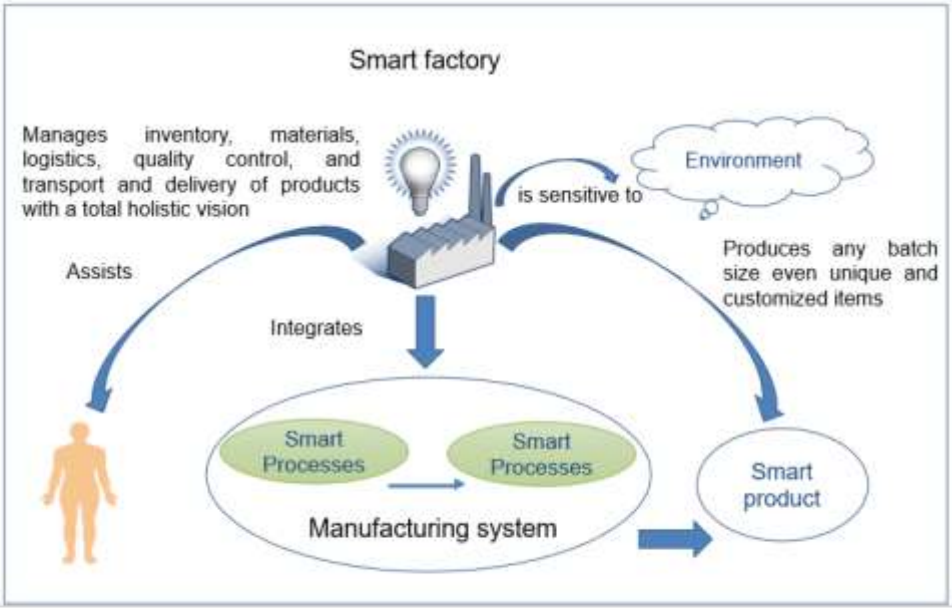

Figure 5. Production directed by the smart factory.

4.3.3 Data

The smart factory maintains information about people, machines, processes, executed tasks and tasks to be executed, in addition to environmental conditions. Every system into the smart factory is aware of its context and considers information such as the position and status of the different elements involved in the manufacturing processes, together with information from the physical and virtual world to fulfill its tasks [16].

The smart factory also retains information about inventories, materials, suppliers, logistics, quality, uptime, and transportation of finished items [30], including all the main structures, systems, and other data about real and virtual resources in conjunction with the product [15].

4.3.4 Connections

Inside the smart factory, humans, devices, and resources collaborate with each other [19]. The smart factory digitizes, integrates, and connects flexible and smart processes across the entire value chain. It means that the smart factory enables a new communication and integration [5] in real time of all facilities, systems, human and manufacturing resources, increasing efficiency, and meeting the requirements of complex markets [28].

4.3.5 Services

The smart factory must include services to know its context and environment, as well as services to assist people, machines, and processes in the execution of their tasks [16]. Additionally, the smart factory must include services to encapsulate and manage aspects such as inventory levels, materials, logistics, quality control, and transportation and delivery of finished products [30], complexity, efficiency, as well as uptime, downtime, and next maintenance operations. The smart factory must also include services that allow the evaluation and continuous improvement of all the main structures, materials, human resources, processes, systems, and other real and virtual resources in conjunction with the product [15]. Finally, the smart factory should make possible to respond flexibly to last minute changes, interruptions and failures coming from machines and suppliers [19].

5. Discussion

Current manufacturing systems have evolved with the arrival of new technologies and manufacturing paradigms, where CPSs have become the key technology to carry out complex scenarios in the fourth industrial revolution. CPSs have different hierarchical levels according to their physical laws, functions, structure, and uncertainty into their environment. These levels are unit, system, and system of systems. Thus, the physical world of a CPS may consist of device, product, operational process, system, and even an organization. Where the main types of CPSs involved in the manufacturing processes are smart factories, smart products and CPPS. These main types of CPSs share the general characteristics of any CPS, such as service orientation, real-time and data-optimized decision making, they are modular, flexible and adapt to their environment, in addition to being autonomous and intelligent systems seeking to increase efficiency and productivity. These CPSs are supported by new manufacturing paradigms to achieve fundamental requirements such as decentralized services and resources in the cloud (CM), providing users with ubiquitous access to CPPS with the ability to design, make, and sell anywhere, at any time (UM). But the full potential in any CPS can only be achieved by the integration between the entity and its corresponding scenarios. While the entity integrates all the information regarding the physical part, the scenarios represent the entire context in which the entity is involved, including static and dynamic information. Then the correct and complete application of a CPS must be focused on scenarios, for example, the control of the production through the factory, the product or via CPPS. Table 1 summarizes the features of production using the main types of CPSs.

Table 1. Main characteristics of the production and processes directed by the main types of CPSs.

	Main features	Holistic vision
Product	Batch size: **1** Cloud access: **Yes** Production type: **Customized** Ubiquitous access: **Yes** Service orientation: **Yes** Intelligence: **Yes**	Knows its status, location, history, previous and future processes and stages, in addition to upcoming maintenance operations. It is able to interact with its environment and define its logistics and delivery route.
System	Batch size: **N** Cloud access: **Yes** Production type: **In mass and flexible** Ubiquitous access: **Yes** Service orientation: **Yes** Intelligence: **Yes**	Enables a new real-time integration of all the resources involved in manufacturing processes, increasing manufacturing efficiency, meeting complex market requirements and providing to the factory with distributed and decentralized intelligence.
Factory	Batch size: **1 and/or N** Cloud access: **Yes** Production type: **In mass and customized** Ubiquitous access: **Yes** Service orientation: **Yes** Intelligence: **Yes**	Evaluation and continuous improvement that includes all the main structures, materials, human resources, processes, systems and other real and virtual resources of the factory in conjunction with the product. It is aware of its environment and has the ability to assist people, machines and processes in the execution of their tasks.

Smart product-driven production has personalization as its primary goal. It means that users may order any function that can be included into the product, while it controls the stages of its production autonomously. These smart products must be integrated in real time with production systems and be able to interact with their environment, monitor their manufacturing phases, and request the necessary resources for their completion. Smart products must have integrated sensors to collect real-time data used to inform about the location, status, and conditions about the environment. Smart products must be uniquely identifiable, can be located at any time, know their history, current status, details of their manufacturing process and alternative routes to reach their target status. In addition, finished items should possess services to optimize the parameters in which they function optimally and services to recognize signs of wear across their life cycle. These services allow optimizing the production in terms of logistics, execution, and maintenance, as well as the integration with enterprise management applications. Finally, smart products have a holistic view that comprises previous and future steps. These steps not only include production phases on an unfinished product, but also future maintenance operations and even the definition of their logistics and delivery route. In this way, the product requests the resources and orchestrates the production processes until completion.

Smart factory-driven production allows information about manufacturing processes to be available when, where and in the way, it is needed within supply chains and product life cycles performed by up to multiple industries. This smart factory enables real-time integration of all manufacturing resources, increasing efficiency. The smart factory aware of its own context and environment is able to assist people, machines and processes in the execution of their tasks, through systems that consider information from the context, such as the position and status of the different elements involved in the manufacturing processes, together with additional information from the physical and virtual world to fulfill their tasks. The smart factory encapsulates and manages aspects such as inventory levels, complexity, materials, logistics, quality control, and transportation of finished products. It also manufactures products more efficiently and is less prone to breakdowns. Smart factories have a modular structure, whose processes are controlled and monitored by CPSs that allow smart and decentralized decisions. The smart factory allows a holistic vision, evaluation and continuous improvement that includes all the main structures, materials, human resources, processes, systems, and other real and virtual resources in conjunction with the product. Finally, smart factories make it possible to produce any batch size, even individual customer requirements can be met, which means that unique and customized items can be manufactured profitably. In this way, it is possible for businesses and processes to allow last minute changes or respond flexibly to changes, interruptions and failures coming from machines and suppliers.

Finally, CPPS-driven production requires the ability to make decisions autonomously, through CPPS that know their status, capacity, different configuration options, and preparation and maintenance plans. These CPPS must be built through processes implemented using modular CPSs, configured with helper functions and integrated synergistically via the infrastructure, achieving better integration between real manufacturing processes and those virtually planned. CPPS empower the factory with decentralized intelligence through optimized and autonomous decisions, transforming the production into intelligent, collaborative, and data-driven manufacturing. These CPPS must be vertically integrated with production and business processes, and horizontally with dispersed and decentralized value chains, but real-time managed since the order is placed, until the order is delivered to the customer.

6. Conclusions

CPSs are the main technology into the new manufacturing paradigms, implementing features such as service orientation, real-time and data-optimized decision making. They are also modular, flexible and adapt to their environment, as well as to being autonomous and intelligent systems seeking to increase efficiency and productivity. Any CPS can be successfully modeled using the five-dimension framework postulated by Greaves. These dimensions consist of the physical element, virtual model, connections, data and services. But the full potential in any CPS can only be achieved by the integration between the entity and its corresponding scenarios. While the entity integrates all the information regarding the physical part, the scenarios represent the entire context in which the entity is involved, including static and dynamic information. Static information includes data such as equipment structure and geographic location, and dynamic information involves data about the environment, energy consumption, operation, among others. Then the correct and complete application of any CPS must be focused on scenarios, such as the control of the production using the main type of CPSs. These CPSs are smart factories, smart products and CPPS. Smart product-driven production has personalization as its primary goal, allowing the user to order any function that can be included into the product, owns a services-oriented approach while product controls the stages of its production autonomously. Smart factory-driven production allows to have the information available when, where and in the way, it is needed. The smart factory integrates all manufacturing resources in real time, increasing manufacturing efficiency. It is aware of its own environment and can assist people, machines, and processes in the execution of their tasks. The smart factory manages aspects such as inventory levels, complexity, materials, logistics, quality, and transportation of finished products. It also manufactures products more efficiently and can produce any batch size (even unique and customized items) profitably and with fewer interruptions. Finally, in the CPPS-driven production, the intelligence is decentralized and distributed throughout the value chain, where horizontal, vertical, and end-to-end integration is a fundamental characteristic. Horizontal integration connects the CPPS with the different IT systems used in the operational and business processes that involve task such as exchange of materials, energy consumption, inbound logistics, outbound logistics, marketing, among others. Vertical integration connects CPPS with the operational systems in the various hierarchical levels. Finally, end-to-end integration enables machine to machine integration on the factory floor, becoming machines in an integral element of the CPPS. Secondly, it integrates clients into the manufacturing system, thus allowing engineers and producers to get feedback from clients easily and in right time. Finally, it enables a product-to-service integration, allowing to producers to monitor the condition of the product in use.

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