Integrated Product, Process and Manufacturing System Development Reference Model to develop Cyber-Physical Production Systems – The Sensing, Smart and Sustainable Microfactory Case Study

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Abstract: This work provides a systematized process for the Sensing, Smart and Sustainable Product Development (S³-Product) applied to develop Cyber-Physical Production Systems (CPPSs). This reference framework is based on the Integrated Product, Process, and Manufacturing System Development Reference Model (IPPMD). The IPPMD will permit the integration between the different engineering domains that comprise the S³-Product (mechanical, electrical/electronic and software engineering). Therefore, the framework proposed provides a set of stages, activities, and tools in order to guide designers in the S³-Product realization process. The main objective of this work is to fill the lack of design roadmaps that permit the realization of this new generation of products. A development of a S³-Microfactory as CPPS is presented as case study.

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Keywords: Internet-of-Things, Cyber-Physical Systems, Cyber-Physical Production Systems, Sensing Enterprise, Smart Enterprise, Sustainable Enterprise, Digital Enterprise

1. INTRODUCTION

Today, enterprises must shift their strategies and tactics in order to remain competitive in the marketplace. Therefore, new business rules, practices, and technologies have been emerged. In this context, the new product development (NPD) is used as strategy to offer a new generation of products in order to face the dynamic market change and respond to the current demand of customers. This new generation of products mostly have a technology-based and consider sustainable objectives. Thus they permit consumers not only to satisfy a need but also to take advantage of all resources they have such as modularity, flexibility, connectivity, customization, environmental care and so forth. Hence, it is necessary to offer new approaches that incorporate emergent technologies and consider desirable features of new products. In this work, the sensing, smart and sustainability concepts have been considered for the design and development of this new generation of products. The sensing concept means the capability that a product has to monitor its functionality, so main objective is to collect data from an environment in order to provide accurate information that will be used to improve the product functionality such as optimization, monitoring, control, and autonomy. Consequently, consumers will take advantage of the resources offered by the product and also will support to reduce environmental damage. The smart concept is applied to design and develop products enabling to work in an interconnected environment. Hence, connected products offer exponentially expanding opportunities for new functionality, greater reliability, higher product utilization, and capabilities that cut across and transcend traditional product boundaries. Also, this concept is applied to improve the decision-making process in order to enhance the product performance. And the sustainability concept is related to design sustainable products and manufacturing processes pursuing environmental, social and economic objectives (Haapala, et al., 2013).

In this paper is presented the S³-Product Development Reference Framework to develop Cyber-Physical Production Systems (CPPSs). The reference framework proposed is based on the Integrated Product Process and Manufacturing System Development Reference Model (IPPMD) (Molina, 2012). In the IPPMD reference model all the product lifecycle stages are mapped and depicted in a concurrent engineering process, and traces the activities of cross functional teams during the product development. The IPPMD provides a generic model composed of three axes: Stages (ideation, basic development, advanced development, and launching), Views (function, information, resources, and organization), and Processes (product development entity, manufacturing process entity, and manufacturing system entity). Therefore, it is possible to design and develop products, manufacturing process and manufacturing systems in a holistic way. Thus the S³-Product Development Reference Framework is used to develop the S³-Microfactory as CPPSs which is presented in this paper as case study.

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10.1016/j.ifacol.2017.08.006
1.1 Cyber-Physical Production Systems

The 4th industrial revolution (Industry 4.0) is driven by the Internet. Thus it is supported by concepts such as CPS, Internet of Things (IoT) and Internet of Services (IoS) (Gilchrist, 2016). The CPS are “systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet” (Monostori, 2014; Monostori, 2016). Also, CPSs can be characterized as physical and engineered systems whose operations are monitored, controlled, coordinated, and integrated by a computing and communicating core (Rajkumar et al., 2010). Today, there are many applications of CPSs in different sectors such as smart transportation, navigation, agribusiness, medicine, logistics, among others, but its implementation in the manufacturing sector has determined the born of CPPSs. CPPSs consist of autonomous and cooperative elements and sub-systems that are getting into connection with each other in situation dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks (Monostori, 2014; Monostori, 2016). In this paper the CPPS concept is applied to develop a Sensing, Smart and Sustainable Microfactory (S3-Microfactory).

1.2 Sensing Products

Sensing Products are using sensors to detect events and measure changes that occur in an environment. Thus the data collected will be processed in order to improve product functionality (e.g. monitoring, control, optimization, autonomy) (Porter et al., 2014). Sensors are related closely to smart products because both are necessary for interaction with an interconnected environment and for support the decision-making in the smart module. Advances in sensors technology permit to increase their processing and capability and decrease their size, energy consumption, and cost. Therefore, technologies such as sensor networks (SNs) and wireless sensor networks (WSNs) have been more used for interconnected applications; both allow to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion, etc. (Weichhart et al., 2016; Molina et al., 2014). Also, new wireless communication technologies allow implementations in different sectors for example in wearable and implantable biosensors, along with recent developments in the embedded computing, intelligent systems, and cloud computing areas are enabling the design, development, and implementation of higher level systems for IoT (e.g., M2M and CPS).

1.3 Smart Products

Smart products are physical products which are equipped with embedded systems, sensors and actuators. Janzen, S., et al., (2008) mention that “Smart Products connect the drafts of physical products and information goods and allow the embedding of digital product information into physical products.” According to Porter, M. E., et al., (2014) a smart product has three core elements: physical components (mechanical and electrical/electronic parts), smart components (control systems, sensors, microprocessors, data storage, software, and user interface), and connectivity components (ports, antennae, and wired or wireless communication protocols).

Reiner, A., et al., (2013) mention that smart products incorporate the concept of CPS that means an integration of computation, networking, and physical process. In this sense, the use of WSNs in CPS has been increasing due to the benefits they provide such as ubiquity, low cost, and flexibility (Wright, 2014). Valencia, A., et al., (2015) mention that a product could be smart if it uses Information and Communication Technologies (ICTs). Thus, they propose the concept of Smart Product-Service Systems (SPSS), which integrates products and e-services into single solutions. Also, products that are using the machine to machine (M2M) technologies are referred such as smart products. Also, some authors mention that a smart product also could be composed of smart materials (Breunis et al., 2014; Van der Auweraer et al., 2013). In the manufacturing context, a smart product is defined as the ability that a product has to know its state, its position, its history, its target product and its flow alternatives (Wright, 2014; Almada-Lobo, 2016; Mauricio-Moreno et al., 2015). According to Molina, A., et al. (2014) the smart concept is related to giving intelligence to a system. Thus the decision-making process is using specific control algorithms such as artificial intelligence such as fuzzy logic, genetic algorithms, among others and it has a crucial role within the information-processing stage.

1.4 Sustainable Products

Sustainable products are products that balance their environmental performance with social and economic objectives (Haapala et al., 2013). Therefore, they pursue reducing the environmental impacts throughout the efficient use of materials, energy, and manufacturing processes. The social aspect is related to the contribution of the product for quality of life of people and it considers areas such as health, education, culture, housing, through of three essential aspects employee, customer, and community (Joung et al., 2013). Finally, the economic aspect is related to productivity, development of low-cost products, the birth of enterprises, employment generation, profitability, among others (Gupta, 2015).

In order to pursue the sustainability in the NPD process, there are resources that support the product design and development process. Thus techniques and tools such as eco-design, sustainable design, design for environment (DFE), and the life-cycle assessment (LCA) have been used; these resources allow designers to measure and to evaluate sustainability during the product development process and also during its manufacturing process. So then, it is necessary to identify specific indicators and metrics for measuring the different impacts. In this way, it is possible to get control over sustainability aspects during the product development process. Some of the main indicators to evaluate in the environmental aspect are: emissions, pollution, resource
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