Smart Factories in Industry 4.0: A Review of the Concept and of Energy Management Approached in Production Based on the Internet of Things Paradigm

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Abstract - **The real and the virtual worlds are growing speedily and closely to form the Internet of Things (IoT). In fact, IoT has stimulated the factories and the governments to launch an evolutionary journey toward the fourth industrial revolution called Industry 4.0. Industrial production of the new era will be highly flexible in production volume and customization, extensive integration between customers, companies, and suppliers, and above all sustainable. Reviewing and analyzing the current initiatives and related studies of the smart factories/Industry 4.0, this paper presents a reference architecture for IoT-based smart factories, defines the main characteristics of such factories with a focus on the sustainability perspectives. And then it proposes an approach for energy management in smart factories based on the IoT paradigm: a guideline and expected benefits are discussed and presented.**

Keywords – **Internet of Things, smart factory, energy management**

I. INTRODUCTION

New market requirements and emerging autonomously technologies such as IoT are shifting the manufacturing companies' environment toward smart factories. The basic idea of IoT is a system where the physical items are enriched with embedded electronics (RFId tags, sensors, etc.) and connected to the Internet. So, IoT relies on both smart objects and smart networks [1]. Thanks to IoT physical objects are seamlessly integrated into the information network where they can become active participants in business processes [2], communicate information about their status, surrounding environment, production processes, maintenance schedule and even more. On the other hand, rising energy prices, increasing ecological awareness, and changing consumer behaviors toward greener products are driving decision makers to put green manufacturing and energy efficient production processes at the top of their priorities. Green products defines in [3] as that have been manufactured consuming as little energy as possible, not only the products which consumes less energy when used by the customer.

An area where IoT will play a major role is in smart meters [4] [5], thus enabling energy consumption data collection in real time (e.g. at machine, production line and facility level). In order to improve energy efficiency, this data will then have to be integrated in the production management practices and decisions.

II. METHODOLOGY

Based on reviewing the literature and current projects that are targeting IoT-based smart factories (i.e. industry 4.0); this paper aims to illustrate the concept of industry 4.0 by presenting the architecture for IoT-based smart factory, and defining the main characteristics of such factories with reference to energy management. Since the smart factories are considered sustainable, and at the same time IoT is the main enabler technology for smart factories. This paper shows how IoT will improve energy efficiency by proposing an approach to support IoT-based energy management in (sustainable) smart factory through integrating energy data in production management. Fig. 1 shows the research focus in the paper. In order to test the proposed approach and assess its impact on improving energy efficiency; a pilot study was carried out in a discrete manufacturing company in Spain. Several smart meters have been installed at machine level to collect energy consumption data in real time, and then this data have been analyzed and provided to decision makers to improve energy efficiency by integrating them in production management decisions.

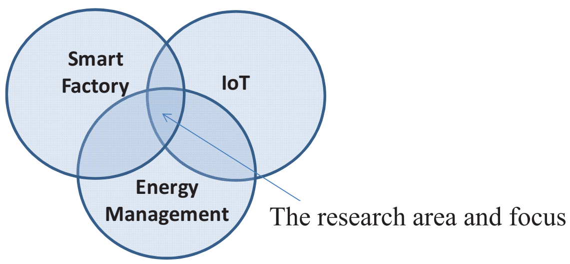

Fig 1. Research focus

III. INDUSTRY 4.0

A. Historical, Motivation, And Benefits of IoT-Based Smart Factories Industry 4.0

The first industrial revolution began with the introduction of mechanical manufacturing equipment, followed by a second one that involved mass production of goods. Since early 1970s right up to the present days, increasing automation and control of manufacturing processes by employing electronics and IT is considered the third revolution (digital revolution). Harnessing IoT

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technology into the manufacturing environment can lead towards the fourth stage of industrialization [2] [6] [7] [8].

According to a survey by American Society for Quality (ASQ) in 2014, 82 percent of organizations that claim to have implemented smart manufacturing say that they have experienced increased efficiency. 49 percent experienced fewer product defects and 45 percent experienced increased customer satisfaction" [9]. Also, the Economist Intelligence Unit estimated the current and future use of the IoT through running a survey in June, 2013 on the global business community: according to their results, 38 percent of respondents believe that the IoT will have a major impact in most markets and industries. Three years from survey time, 96 percent of the respondents expect their business to be using the IoT in some respect, 63 percent believe that "companies slow to integrate the IoT will fall behind the competition" and 45 percent believe "adopting the IoT will make their company more environmentally friendly" [8].

B. What is Industry 4.0?

The basic principle of Industry 4.0 is the core of IoT and smart manufacturing [10]: work in progress products, components and production machines will collect and share data in real time. This leads to a shift from centralized factory control systems to decentralized intelligence [11]. The German Federal Ministry of Education and Research defines Industry 4.0 as "the flexibility that exists in value-creating networks is increased by the application of cyber-physical production systems (CPPS). This enables machines and plants to adapt their behavior to changing orders and operating conditions through self-optimization and reconfiguration … The main focus is on the ability of the systems to perceive information, to derive findings from it and to change their behavior accordingly, and to store knowledge gained from experience. Intelligent production systems and processes as well as suitable engineering methods and tools will be a key factor to successfully implement distributed and interconnected production facilities in future Smart Factories".

Since exchange data and information between different devices and parties in real time is the key element of smart factories; such data could represent production status, energy consumption behavior, material movements, customer orders and feedback, suppliers' data, etc. The next generation of smart factories therefore will have to be able to adapt, almost in real time, to the continuously changing market demands, technology options and regulations [12].

Fig. 2 shows a relation between smart factories and customers in industry 4.0 that is enabled by IoT technology. The smart factories provide the customers with smart products and services which will be connected to the internet. Then, the smart factories will collect and analyze data coming from the smart products and related smart applications. This analysis enables the factories to better define customers' behaviors and needs, and to provide them with new and more sustainable products and services. In addition to that, IoT technology enables the customers to be involved in production design process.

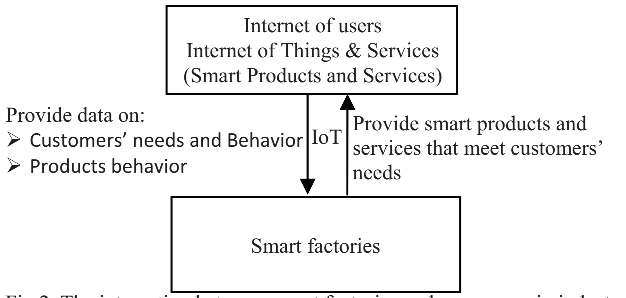

Fig 2. The interaction between smart factories and consumers in industry 4.0.

C. A Reference Architecture for IoT-Based Smart Factory

Fig. 3 presents a reference architecture for IoT-based smart factory in industry 4.0. It includes several sets of technology and several perspectives [6], as the following

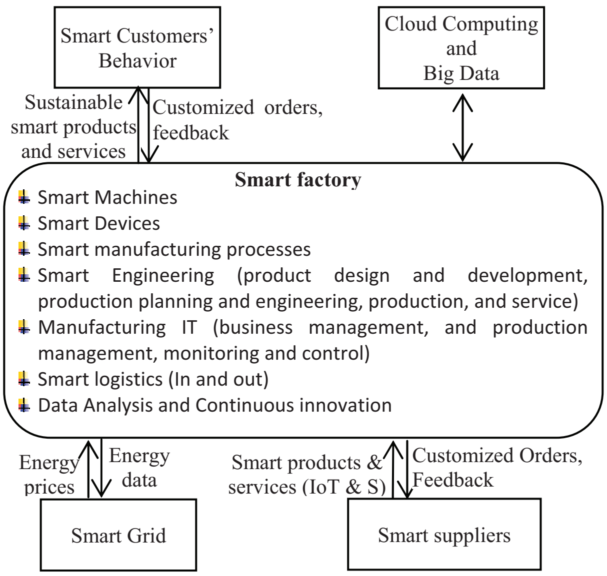

Fig 3. Reference architecture for IoT-based smart factory

Smart Machines: include M2M communication, machines communicating with other devices and humans.

Smart devices: includes connecting devices in the factory such as field devices, mobile devices, operating devices, etc.

Smart manufacturing processes: include dynamic, efficient, automated and real-time process communication for the management and control of a highly dynamic manufacturing environment enabled by IoT.

Smart Engineering: includes product design and development, product engineering, production, and after sales service. This could require the use of collected data from the manufacturing process in planning process, and optimize machines (mechanical, electrical, etc.).

Manufacturing IT: includes first, software applications used by one or more businesses supporting value networks; second, smart monitoring and control through sensors, smart meters and smart mobile devices; third intelligent production management, which integrate data from IoT into production management logic.

Smart logistics: include smart logistics tools and processes. Self-organized logistics is an example of smart internal logistics that react to unexpected changes in production, such as bottlenecks and materials shortages [10].

Big Data and the Cloud computing Data: include algorithms, analysis applications, etc. Big Data analytics will bring profound opportunities for improving future factories, manufacturing processes, and enable factory to provide new products as shown in Fig 2.

Smart suppliers: include building sustainable relations with suppliers. E.g., by increase information sharing in real time; similarly, increase flexibility by selecting the best supplier based on factory needs.

Smart Grid: includes the smart infrastructures of smart factory in field of energy supply. In particular, it is essential to react to changes in energy prices (i.e. demand-side management).

D. Characteristics of Smart Factories

This section discusses the main potential characteristics of smart factories in industry 4.0, highlighting how these characteristics can improve the sustainability of smart factories.

➢ *Mass customization*

Production processes have to meet varying requirements of production orders [11]. It allows individual to be included in the design, and enables last-minute changes. It is possible to have low production volumes (e.g. batch size of 1) whilst still making a profit [6]. Hence, Mass Customization (MC) concept can be used to manage the disproportion between the economies of scale and scope, which has been discussed widely in the literature such in [13] and now research focus is shifting to how a MC business model performs in terms of environmental sustainability.

➢ *Flexibility*

Intelligent production processes, and self configuration have to consider different aspects [14], such as time, quality, price and ecological aspects (e.g. avoid peak time, etc.).

➢ *Factory visibility and optimized decision-making*

Take the right decisions at anytime is a key to succeed in the market. IoT provides end-to-end transparency almost in real time (e.g. production status), allowing for optimization across factory sites in the area of production, and then improve factory efficiency [2]. For example, reducing waste by provides decision maker with the production status in real time, where using mobile technology leads to shrink the time between problems occurs and make the efficient decisions. In such cases the machine can be shut down before it continues to produce defected products. Moreover, the transparency includes awareness of energy consumption behavior of production processes. Here, energy data can be considered in production management decisions, so as to reduce energy waste and consumption costs.

➢ *New planning methods for factories*

"The use of abstract planning procedures based on digital models with a stronger parallelization considering the planning of mechanical and electronic systems" [14]. Furthermore, for resource productivity and improve energy efficiency purpose; it is necessary in smart factories to allow manufacturing processes to be optimized at different levels in real time and on a case-by-case basis. Also, when there is fluctuating in energy purchasing prices, the availability of energy consumption data from IoT can be consider to minimize energy consumption costs of production schedule by defining the launch time for job processing as in [15].

➢ *Creating values from big data collected*

New improvements and value can be provided by the analysis of large quantities of collected data by IoT devices (i.e. big data). For example, at machines' provider side, big data can be used to understand the machines behavior through different periods. Accordingly, those providers can provide best maintenance services, and improve machines efficiency, and build strong relationship with their customers.

➢ *Creating new services*

IoT (e.g. smart devices and mobile applications) will open up new ways of creating services and values for the customers before and after purchase.

➢ *Remote monitoring*

IoT technology will enable involvement by third party (e.g. suppliers) in monitoring, operating and maintenance of factories with new services.

➢ *Automation and change role of man*

Production operations can be optimized with a minimum intervention of human. This could improve the efficiency and reduce errors and waste in energy and other resources.

➢ *Proactive maintenance*

Monitoring production system and collecting performance data in real time have positive impact on improve proactive maintenance. For example using sensors to monitor temperature, preemptive actions can be taken when it goes out of range and prevent breakdown. As well as, preemptive actions can be taken too, when energy consumption jumped above normal level for a period for time. This will save energy, reduce waste of defect products, and avoid breakdown the machine. Furthermore in [10] describe IoT-enabled vision where machines predict failure and trigger maintenance processes autonomously.

- *Connected Supply Chain*

IoT will help manufacturers gain a better understanding of the supply chain information that can be delivered in real time. By connecting the machines and equipment to suppliers, “all parties can understand interdependencies, the flow of materials, and manufacturing cycle times” [10].

- *Energy management (HVAC, and production)*

Energy efficiency improvement requires awareness of energy consumption behavior at production line and machine level [16]. Smart meters can provide real time data, and take decisions based on their capabilities and in collaboration with external services [5]. In fact, There are several sustainable practices that can be adopted based on adopting IoT technology for improving energy efficiency at production level (e.g. avoid peak time, integrate energy data in production schedule, etc.) [17]. As well, it enables an automation of environmental controls in factory, such as HVAC.

IV. How IoT will Support Energy Management in Smart Factories

The lack of understanding of the energy consumption behavior “who”, “where”, “when”, and “how” is the essential reason of the difficulty in evaluating and improving factory energy efficiency. In order to improve energy efficiency, significant attention and efforts have to be made to obtain energy data from smart meters, sensors, and other tools [18], and then integrate this data in production management. The resort to IoT technology will change the conventional paradigm of energy measurement [19].

Moreover using smart meters and sensors enables remote monitoring of energy consumption data across the factory. The data can then be stored and analyzed on the cloud. The results and warring messages can be delivered through mobile applications to shop floor supervisor. Also, energy management experts can make real time assessment by having clear picture of energy consumption in real time.

As a result of the study in the factory, Fig. 4 presents an approach to support IoT-based energy management in sustainable smart factory. It shows four phases to be followed in the adoption process. The first phase involves the understanding of the production processes, the evaluation of the current energy management practices and the definition of improvement targets. The second phase focuses on collecting (possibly) real time data by means of IoT technology and then analyzing them to understand current practices and limitations. Here it is required to define the machines that will be monitored; define a list of required measures (active power, reactive power, etc.); define the monitoring devices for each machine, its specifications; and the communication system; and define where and how the data will be stored and analyzed. Moreover the production processes have to be identified (e.g. production sequence, processing time for each product under different machine configuration), so as to link and understand the energy consumption behavior and make the efficient decision. After collecting and analyzing the data, the third phase is to integrate this data into energy management tools (e.g. energy decision support system, simulation tools) to enable the decision makers to define the waste of energy consumption, where improvement can be achieved, also select the most sustainable configuration mode of machines with considering the production planning in order to improve energy efficiency. The fourth phase encompasses the upper level, i.e. the definition of strategies and practices to improve the energy efficiency of the smart factory “by design”, for example by integrating energy data in production management practices.

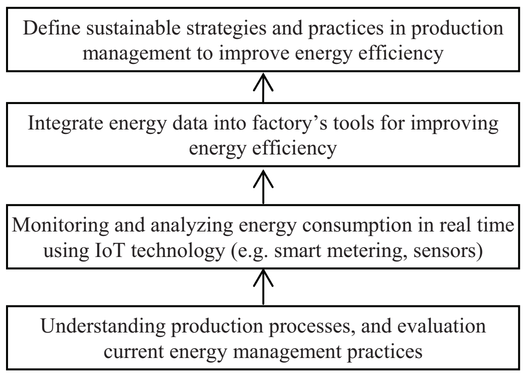

Fig 4. Approach for improving IoT-based energy management in smart factory

During the implementation of the above approach, several operations management practices have been enhanced by integrating energy data. For example, energy consumption data has been collected from the machines under different configurations (e.g. machine speed). Then, based on the flexibility of production schedule, this data enabled the production manager to select the most efficient configuration of the machines. Moreover, the analysis of energy consumption data provided the decision makers with a clear picture on the energy waste at production level (e.g. idle time), and it provided precise information about the energy needed to produce one piece.

V. CONCLUSION

This study presents an overview of smart factories (Industry 4.0), the architecture for IoT-based smart factories, and the characteristics of such factories with a focus on the sustainability aspects. Besides that, it introduces an approach to adopt IoT paradigm at production level in order to support energy management and increase energy efficiency of production systems at such factories. By collecting energy consumption data from shop floor (e.g. at production line, machine, processes level etc.), and by providing them to decision makers in real time at any place (e.g. using mobile device) and eventually integrating energy data in production management practices energy efficiency can be improved, through find and reduce the wastes and enable energy-aware decision-making at production management level (e.g. production scheduling, and maintenance management, etc.).

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