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Internet of Things in product life-cycle energy management

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ABSTRACT

Internet of Things (IoT) as a new emerging and fast growing technology has attracted lots of attention from worldwide recently. Successful applications of IoT have been demonstrated in many fields. However, IoT is still at its infant stage when it comes to the applications in product life-cycle energy management (PLEM). In this paper, the concept, characteristics, and applications of IoT are briefly introduced first. Then, the energy consumption involved in the three phases of product life cycle (i.e., design, production, service) are concluded and analyzed. But what is the relationship between product lifecycle energy consumption and the IoT technology? Whether the IoT concept and techniques can be employed in manufacturing to reduce the energy consumption during design, production, service process, and what are the potential applications? Therefore, in order to answer these questions, the existing applications of IoT in PLEM are summarized, and the potential applications and challenges of IoT techniques in PLEM are analyzed and pointed out.

1. Introduction

Manufacturing plays an indispensable role within the global economy. But in recent years, natural resources are being depleted rapidly along with all sorts of environmental consequences and social problems largely because of the development of manufacturing. Trusting data shows that the industry sector, which currently consumes about 37% of the world's total delivered energy, uses more energy than others. Among the energy consumption in industry, manufacturing accounts for a high percentage [18,30,75]. Analyzing from the proportion which manufacturing energy consumption account for the total energy consumption, we can take The United States and China as examples. The United States is the largest energy consumer in terms of total use. In 2006, industry in the United States takes about 32.55% of the gross energy consumption. Manufacturing takes about 65.14% of the industrial use as shown in Fig. 1 (EIA http://www.eia.gov/totalenergy/data/monthly/pdf/sec2_3.pdf). In 2014, the United States's industry sector is responsible for 32.09% of the total energy consumption.

China's industry sector is extremely energy-intensive and accounted for 69.83% of the country's total energy consumption in 2013. Manufacturing is responsible for 57.33% of the total use as shown in Fig. 2 (http://www.stats.gov.cn/tjsj/ndsj/2015/html/CH0909.jpg).

In this background, avoiding energy waste and optimizing product life-cycle energy management are of the utmost importance to cope with the increased global adverse environmental impacts. Energy savings are expected to be achievable both from the improvements in energy efficiency of certain production processes, as well as from the usage of effectual energy monitoring systems and management [68]. However, in many manufacturing factories, energy management from product life-cycle management (PLM) suffers to the lack of awareness of energy consumption. Even worse, it is common that some manufacturers neither try to find out the energy consumption sources nor availably analyze energy data just because they think there is no convincing effective way to manage the energy consumption. This understanding is absolutely not profound enough.

A new emerging technology named IoT holds great promise in handling the above mentioned issues almost in real-time. "IoT" as an umbrella keyword for covering various aspects related to the extension of the Internet and the Web into the physical realm, by means of its widespread deployment of spatially distributed devices with embedded identification, sensing and/or actuation capabilities [48], has caught countless people's eyes both in academic and industrial community recently. Besides, after the breakthroughs from large-scale integrated circuits, personal computers, and the Internet, many speculators believe that the ongoing breakthrough in IT infrastructure is IoT. As for its potential to manufacturing, with the IoT technology, the raw material, component, machine, product and facilities can all be equipped with

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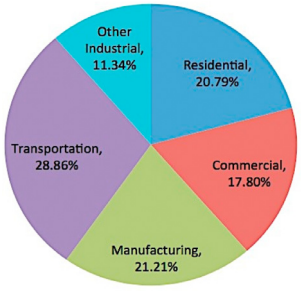

Fig. 1. Energy Consumption by Sector in the United States.

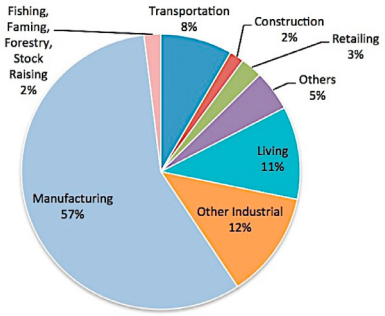

Fig. 2. Energy Consumption by Sector in China.

embedded intelligent devices so that energy parameters connected to the manufacturing process can be acquired in real time, the storage and collection of critical information about the usage and condition of an individual item are enabled, and the detection and take-back of the end-of-use products are facilitated.

Although the concept of "IoT" in PLEM is quite a new idea, a number of papers related to product life cycle assessment, energy monitoring and process optimization have been published in recent years. The following two aspects are summarized as the existing applications of IoT in PLEM.

1.1. Monitoring of energy consumption based on IoT

IoT technology provides awareness of energy consumption patterns by collecting real-time energy consumption data. Then the energy consumption status of objects can be well monitored during the whole product life cycle.

1.2. Object tracking based on IoT

IoT technology makes it possible to control the energy consumption more accurately by real-time tracking of product through technologies such as radio frequency identification devices (RFID).

Although the existing research works about IoT have largely improved manufacturing management, IoT-based energy management is still at a primitive stage in the mass. Developing IoT-based PLEM is an efficient way to realize better energy management. Thus, academic research studies about IoT in PLEM are extremely valuable and pressing.

Therefore, to complete the lack of academic studies of IoT in PLEM, it is necessary to give a comprehensive and systematic framework of the detailed applications of IoT in PLEM. In this framework, PLEM is divided into three parts from the product life cycle, then energy consumption and IoT-based energy management in each corresponding detailed available step is given. Actually, not all of the divided steps are suitable for IoT employment which may increase workload and difficulty to distinguish the potential ones from the improper ones. Aiming at each potential one, the existing and promising applications of IoT are introduced and analyzed thoroughly. In a word, the purpose of this paper is to provide a roadmap to direct and guide the related research works in the future.

The rest of the paper is organized as follows. Section 2 introduces the concept, brief history and some applications of IoT. Section 3 investigates the energy consumption in product life cycle. Section 4 studies the role that IoT plays in energy management, and presents the application of IoT in PLEM. Section 5 demonstrates the challenges of IoT-based PLEM. Finally, future research issues and direction about IoT in PLEM are concluded and discussed in Section 6.

2. IoT

2.1. Concept of IoT and its brief history

2.1.1. Concept of IoT

In academic community, IoT has been defined from various different perspectives so that numerous definitions for IoT exist in the literature. The difference results from the development of the IoT.

The term IoT was firstly proposed by Kevin Ashton in MIT Auto-ID in 1999, he emphasized using the IoT to mark the characteristics of objects and defined IoT only based on RFID technology to realize the interconnection of objects [65]. Melon Steven in SUN considered that the IoT is using RFID electronic tag to make the computers automatically identify common objects and then tracking, monitoring, and managing [47]. The formal IoT concept was given by ITU in WSIS in 2005 as realizing people and things' interaction in any time and any place by embedding short-distance mobile transceivers into parts and daily objects [73]. In 'Internet of Things in 2020' [7] European Union came forward that IoT is a network consisting of objects with label or virtual character, where the label and personality are stored in smart space using intelligent interface to communicate with users, society and environment. The CEO of IBM ales used his definition of IoT to describe the Smarter Planet plan [24].

Till now there is no accepted or standard definition for IoT. A relatively convincing definition of IoT focuses not only on object identification and interconnection but also on the role of communication network. For example, the definition by Miragliotta [49] illustrates that IoT is a paradigm realizing the interplay of smart objects and of smart communication networks. Atzori et al. [5] define IoT as pervasive presence around us of a variety of things or objects such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc. which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbors to reach common goals.

2.1.2. Brief history of IoT

The development of IoT can be traced back to a few years ago. The recognized first work exploring RFID is the landmark paper by Harry Stockman in 'Communication by Means of Reflected Power' [72] which was published in 1948. Since then, many researches based on RFID have been conducted. At the same time, many large companies managed to develop RFID technology, such as Raytheon's Raytag in 1973 [87] and Richard Klensch of RCA developing an electronic identification system in 1975 [38]. In 1987, Sakamura in Tokyo [64] advocated an open-architecture computer system named TRON to build environment making the recognizer identify all items. In 1991, the first ETC (Electronic Toll Collection) system in the world was established in Oklahoma in USA [22]. In the same year, Mark Weiser [81] predicted the promising and worldwide application of computers in his article "The computer for the 21st century"in Scientific American. In 1995, Bill Gates mentioned the concept of IoT in his book the Road Ahead