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A Framework of Energy Consumption Modelling for Additive Manufacturing Using Internet of Things

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Abstract

The topic of 'Industry 4.0' has become increasingly popular in manufacturing and academia since it was first published. Under this trending topic, researchers and companies have pointed out many related capabilities required by current manufacturing systems, such as automation, interoperability, consciousness, and intelligence. Additive manufacturing (AM) is one of the most popular applications of Industry 4.0. Although AM systems tend to become increasingly automated and worry less, the issue of energy consumption still attracts attention, even in the Industry 4.0 era, and is related to many processing factors depending on different types of AM system. Therefore, defining the energy consumption behaviour and discovering more efficient usage methods in AM processes is established as being one of the most important research targets. In this paper, an Internet of Things (IoT) framework is designed for understanding and reducing the energy consumption of AM processes. A huge number and variety of real-time raw data are collected from the manufacturing system; this data is analysed by data analytical technologies, combining the material attributes parameter and design information. This data is uploaded to the cloud where more data will be integrated for discovering the energy consumption knowledge of AM systems. In addition, a case study is also presented in this paper, which a typical AM system is focused on the target system (EOS P700). The raw data is collected and analysed from this process. Then, based on the IoT framework, a novel energy consumption analysis proposal is proposed for this system specifically.

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Keywords: Energy Consumption, Additive Manufacturing, Internet of Things Framework

1. Introduction

Nowadays, Industry 4.0 is not only a research and development slogan but is also an industrial and academic activities. Many companies and research organizations have begun working on this forward topic including various aspects [1; 2]. With more and more related publication of technologies, principles, and concepts, the achievement criteria of Industry 4.0 has become much clearer and more specific. A qualified Industry 4.0 manufacturing system needs necessary capabilities, like interoperability and consciousness. To achieve these capabilities, data is considered as being vitally important. It is the connecting media of the integration between different manufacturing objects and activities. Enabling technologies are included in manufacturing such as; the Internet of Things (IoT), Data Mining (DM), and Big Data (BD) [3]. With the development of digital manufacturing, the current manufacturing is settled in the big data environment. It is summarized as the great volume, various modalities, high velocity, and huge value data environment [4]. This big data is generated by both production processing and other manufacturing events such as product design, production planning, energy supply, marketing, and customers' reviews [5]. In an industry 4.0 factory, the data is collected and tabulated, and valuable information can be extracted and used to improve processes.

Although Industry 4.0 manufacturing is integrated, automated, predictive, and intelligent it has to be sustainable and renewable [6]. At present, industrial production activities use about 35% of the entire global electricity supply, which produces approximately 20% of total carbon emissions. In the last 20 years, there has been an increase of more than 50% in greenhouse gas emission is released by the top five manufacturing countries. The manufacturing sustainability has

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never escaped industry's attention and is also an indispensable research topic in the age of Industry 4.0. The energy consumption is considered as one of the most crucial fields of manufacturing sustainability. It is known that the energy efficiency of production processing is normally below 30%. For some specific process, the losses of energy are unexpectedly high, for example, the energy loss of rough milling process is about 60%, and the finishing is about 95% [7]. Therefore, much industrial research has been paying close attention to energy consumption and its environmental and financial impact. Highly efficient energy usage can not only reduce production costs, and expand profit margins, but also solve associated environmental and social problems. In most manufacturing systems, energy consumption is part of essential standards to measure the benefits [8]. Additionally, during the past two decades, additive manufacturing (AM) machines are increasingly being employed, due to their digitalization, automation, flexibility, and customization, which are also becoming a popular production system in the modern industry. Comparing with the traditional manufacturing processing, the AM processing is a low energy efficiency system with a high production yield, especially selective laser sintering (SLS) and selective laser melting (SLM) [9]. The energy consumption of AM process is influenced by many factors, and according to the Life Cycle Analysis (LCA) of SLS processing the energy consumption is the most important factor affecting environmental impact [10]. Reducing energy consumption of AM process is one of the necessary research targets for the manufacturing sustainability in the age of Industry 4.0.

This paper tries to solve the industrial sustainability problems in the Industry 4.0 era, specifically, working out the energy consumption problem of AM processes by using IoT technology. In this research, current AM energy consumption analysis models and optimization methods will be discussed and refined in Section 2. Section 3 presents an integrated IoT framework for AM energy consumption analysis including various layers and components. This method follows the Service Oriented Architecture (SOA) approach. It assists people in understanding the energy consumption behaviour, to predict the trends in energy usage and guides people to use energy efficiently. Section 4 deliveries a case study of the SLS system (EOS P700). The raw data is collected from process parameters and the data log files. After analysis of the correlation between the process environment and energy consumption, a particular IoT proposal of energy consumption will be proposed at the end of this section. Section 5 discusses the main function and future work of this research.

2. Literature review of AM processes energy consumption

Additive manufacturing processing is known as a complex system because of complicated material parameters, highly automated levels, and various types of processing technologies. Different processing technologies show different energy consumption performances. Table 1 shows that the energy consumption comparison of three additive manufacturing technologies including SLS, SLM, and electron beam melting (EBM) in experimental measurement [11; 12; 13].

From these experimental measurements, it is clear that the energy consumption has a large range. Even when testing on the same machine and with the same material, the results show a large variation in every experiment. That means the energy consumption of AM processing is challenging to analyse and optimise. Many researchers have shown that energy consumption of AM processing is caused by many different components and impacted by numerous attributes.

Table 1. Energy consumption comparison between different AM processes.

AM Technology	Energy consumption rate	Experiment material	Experiment machine
EBM [11]	61.20 to 176.67 MJ/kg	Ti-6Al-4V	Arcam A1
SLM [12]	96.82to 139.50 MJ/kg	SAE 316L	MMT SLM250 / EOSINT P760
SLS [13]	52.20 to 129.73 MJ/kg	Polyamide	HiQ+HS / EOSINT P390

Fig. 1 displays a schematic layout of the SLS process which is one of the most important and commercial AM processes currently in use. In Fig.1, it is seen that the system consists of many different types of power usage [10; 13]. There are several energy consumers in each power usage, which are also demonstrated in Fig. 1. The heating system, consisting of frame heating, platform heating, and process chamber heating, is responsible for the major of energy consumed in this process. In addition, the laser units, scanner, and laser cooling system are three main power components in the laser system, with the laser cooling system consuming the most of energy in this subsystem. The main energy usages of the build platform system are driving the motors. Feed and recycle system includes the material and inert gas feed and recycle process. There are controllers, electrical elements, and sensors supporting the system controlling and monitoring functions in such an SLS system, which are also a main part of energy consumers [12].

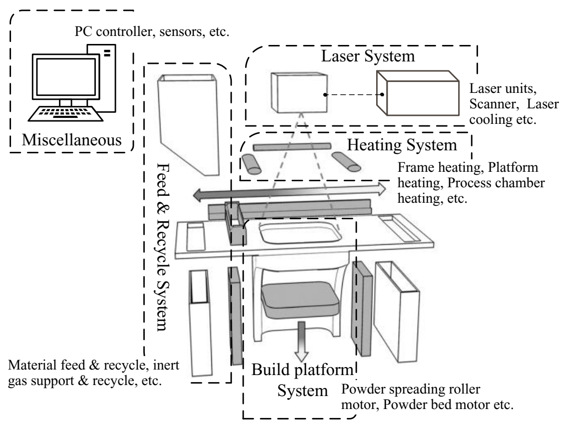

Figure. 1. Main power drains of SLS process adopted from [14].

However, it does not mean these factors related to this system are the only impact elements. Built on the understanding of system and manufacturing experience, a lot of research indicates relationships between energy consumption and