ARTICLE IN PRESS

Robotics and Computer-Integrated Manufacturing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Ubiquitous manufacturing: Current practices, challenges, and opportunities

Toly Chen [a], Horng-Ren Tsai [b,*]

[a] Department of Industrial Engineering and Systems Management, Feng Chia University, No. 100, Wenhua Rd, Taichung City 407, Taiwan
[b] Department of Information Technology, Ling Tung University, No. 1, Lingtung Rd, Taichung City 408, Taiwan

ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form
28 December 2015
Accepted 6 January 2016

Keywords:
Ubiquitous computing
Ubiquitous manufacturing
Cyberphysical system
Sensor
Industry 4.0

ABSTRACT

Ubiquitous manufacturing (UM) features a “design anywhere, make anywhere, sell anywhere, and at any time” paradigm that grants factories an unlimited production capacity and permanent manufacturing service availability. However, the research and applications of UM have been limited thus far to in-factory operations or logistics. For this reason, this study reviews the current practices of UM, discusses the challenges faced by researchers and practitioners, and determines potential opportunities for UM in the near future. Finally, we conclude that the success of UM depends on the quality of the manufacturing services deployed, and that UM is a realizable target for Industry 4.0.

1. Introduction

Ubiquitous computing (UC), or pervasive computing, is a concept in software engineering and computer science in which computing is performed at any location [48]. Ubiquitous manufacturing (UM) is an application of UC in the manufacturing sector that features a “design anywhere, make anywhere, sell anywhere, and at any time” paradigm [19,36]. However, manufacturing a product ubiquitously is not easy. For this reason, UM typically implied that products could be supplied ubiquitously [21]. Nevertheless, with the advances in information, communication, sensing, and networking technology, manufacturing services can now be provided ubiquitously [50].

A concept similar to UM is cloud manufacturing (CM), which enables ubiquitous, convenient, on-demand network accesses to a shared pool of configurable manufacturing resources [50]. In many studies, UM and CM have not been differentiated [36]. However, in contrast to CM, UM emphasizes the mobility and dispersion of manufacturing resources and users. In addition, CM typically deploys cloud services through the Internet, whereas UM does not necessarily rely on a network. For example, Kinect, a sensing system widely applied in UM, does not require network access to operate. Nevertheless, UM and CM benefit from each other. For example, the status of a machine monitored by a ubiquitous sensor can be analyzed using a cloud service.

Foust [21] listed four prerequisite conditions for UM:

(1) Transporting finished goods is more expensive than transporting raw materials.
(2) Finished goods are larger, more fragile, or more perishable than raw materials.
(3) Raw materials are available ubiquitously.
(4) Manufacturers and their customers communicate closely.

These are also called the location controls of UM.

The dynamism and globalization of demand is considered the driving force behind the emergence of CM and UM [36]. Microelectromechanical and radio frequency systems were considered key technologies to UC and UM [35]. Under Web 3.0, a program could run on any device. Thus, Web 3.0 and 4.0 also contributed to the realization of UM [23]. According to Strassner and Schoch [41], automatic identification, localization, and sensor technologies were essential to developing a UC and UM application. Real-time visibility and interoperability were considered core characteristics of UM [53].

Ferreira et al. [23] asserted that CM and UM grants factories unlimited production capacity and permanent manufacturing service availability. In addition, UM was considered capable of sustaining the needed agility and quickness to react to market changes [37]. UM also frees operators from error-prone and time-consuming data collection tasks [53]. However, research into and applications of UM have been limited [26]. Even the most common

* Corresponding author.
E-mail address: horngren.tsai@gmail.com (H.-R. Tsai).

http://dx.doi.org/10.1016/j.rcim.2016.01.001
0736-5845/

Please cite this article as: T. Chen, H.-R. Tsai, Ubiquitous manufacturing: Current practices, challenges, and opportunities, Robotics and Computer Integrated Manufacturing (2016), http://dx.doi.org/10.1016/j.rcim.2016.01.001

UM application, radio frequency identification (RFID), was not common in many regions [52-56]. For this reason, this study reviews the current practice of UM, discusses the challenges faced by UM researchers and practitioners, and determines possible opportunities for UM in the foreseeable future.

The remainder of this paper is organized as follows. Section 2 defines UM and UM systems, and introduces some existing UM systems. Section 3 classifies the technologies for establishing a UM system into several categories, along with their applications. The problems and challenges facing existing UM systems are raised in Section 4, along with their possible solutions. Section 5 discusses potential developments in this field and concludes this paper.

2. UM systems

2.1. Definitions of UM

Various means of defining a UM system exist [36]. The first is to apply UC technologies to a manufacturing system. Huang et al. [25] and Zhang et al. [52-56] have defined a UM system as a wireless sensor network that uses RFID tags and receivers, automatic identification (auto ID) sensors, and wireless information or communication networks such as WiFi or the global system for mobile communications (GSM) to automatically collect, synchronize, and/or process manufacturing data. By this definition, UM is the same as wireless manufacturing [25] or e-manufacturing [8]. UM defined in this fashion is typically confined to the operations of a factory or logistics.

Another definition of UM is to deploy manufacturing resources, services, and/or facilities that use the same raw materials and produce comparable finished goods as ubiquitously as possible [21], that is, the so-called ubiquitous industries. The focus is on internationalization and distributivity [35]. This definition of UM has often been mentioned by geographers. Foust [21] provided an ad hoc definition of UM as a type of manufacturing that is market-oriented and has a frequency of occurrence greater than a specific threshold that can be empirically verified as ubiquitous. Specifically, UM indicates that more than n production locations exist within a country for manufacturing a product. Alexandersson [1] set the threshold for classification as ubiquitous as facilities that can be found in all regions with a population of at least 10,000; as such, only two industries in the United States, printing and publishing and food processing, satisfied his requirement. A critical concern for such a definition is the balance between the locational costs of production and the distribution costs of finished goods. To achieve UM, a hypersized manufacturing network is typically required [36]. An alternative is to form a UM network system through cross-factory or cross-enterprise collaboration.

Putnik et al. [35] defined a UM system as a collection of intelligent devices, logically and/or spatially distributed, that change dynamically and reconfigure automatically for new tasks through the provision of manufacturing services, and are supported by semantic tools for unambiguous communication. This combines the previous two definitions, with a focus on a cyberphysical system (CPS)[1] and Web (or cloud) services.

2.2. Existing UM systems

2.2.1. UM systems based on UC applications

This section reviews some representative cases of the application of UC technologies. Zhang et al. [53] established a real-time work-in-process (WIP) management system for a small flexible manufacturing system (FMS) by using smart objects such as RFIDs and auto IDs and Web services. The FMS was composed of three workstations, one trolley, and one shelf. RFID tags were used to identify operators, components, pallets, and locations on the shelf. RFID readers were integrated with a smart gateway and wrapped with Web services to be easily invoked. Thus, the material flows in the FMS could be automatically traced; the WIP level could be monitored, and, based on the monitoring results, proper shop floor control actions could be taken.

UC technologies have been applied to other places in a factory. For example, Bose and Pal [6] installed auto-ID readers at point-of-sale, storage, and receiving locations to automate data collection. During their investigation, several concerns were raised regarding whether an auto-ID application could be successful, including the acceptable initial investment, item-level or pallet-level tagging, data storage, analysis, privacy, big-band or phased adoption, and integration with existing management information systems (MISs).

In logistics, Prasanna and Hemalatha [34] used RFID tags to identify goods to avoid misplacement, and weight sensors to avoid the overload of vehicles. They also used a global positioning system (GPS) and the GSM to track the locations of vehicles. The weight sensors were connected to a PIC 16F877A microcontroller. The GPS receivers were also connected to the microcontroller with SN74HC00 gate integrated circuits. Thus, heterogeneous information sources were aggregated to facilitate decision making.

2.2.2. UM systems that deploy manufacturing facilities ubiquitously

An experimental LEGO ubiquitous assembly system was established by several universities and institutes; in it, a customer browsed an online catalog and placed an order that could be fulfilled by any of the participating universities or institutes [35]. Despite the limited attempts, manufacturing facilities have only been deployed ubiquitously in the newspaper publishing, bakery, and dairy industries.

The ease of installing and using a three-dimensional (3D) printer and the convenience of exchanging a 3D model online are cultivating additive-manufacturing-based UM systems. For example, websites like My Mini Factory (www.myminifactory.com) and shapeways (www.shapeways.com) gather 3D models from volunteers worldwide, such that a 3D model can be downloaded from the website and printed out at any place and time. By contrast, websites such as 3D Hubs (www.3dhubs.com) work with 3D printing facilities worldwide; customers can determine the 3D printing facility closest to their location and print the 3D model they select from (or upload to) the website.

2.2.3. UM systems based on CPSs and web (and cloud) services

MacGregor Cranes, a crane manufacturer, designed and installed a remote diagnostic system onto each of its cranes to provide predictive maintenance services to customers [26]. The remote diagnostic system included sensors to monitor the temperature, pressure, speed, and usage time of a crane, which were transmitted to MacGregor Cranes (or another service provider) via GSM or a satellite modem. Urgent problems or errors could be discovered by occasional readings of the different parameters. To prevent a potential breakdown, an analysis of long-term data was required. Two ways of applying the remote diagnostic system, creating different values for a factory, were also compared by Jonsson et al. [26]. Conversely, data security and privacy, depersonalization of the service experience, and error-prone sensors with a limited capability were some of the shortfalls of the remote diagnostic system.

To apply cloud services to assist in the predictive maintenance of a machine, information sharing and interactions between the

[1] A CPS is a system of collaborating computational elements controlling physical entities [28].