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A ubiquitous manufacturing network system

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ABSTRACT

In this study, a ubiquitous manufacturing network system was constructed. In this system, a customer places an order for an action figure by using a client-side app or a Web-based interface and pays online. The system server then assigns the order to the convenience store nearest the customer's location to print the required action figure. For determining the most suitable convenience store, a fuzzy integer-nonlinear programming model was proposed and solved using two modified fuzzy Dijkstra algorithms. Subsequently, the customer is informed of the location of and route to the recommended convenience store. Two illustrative cases were used to verify the applicability of using the proposed methodology. In addition, compared with an existing mobile guide, the proposed methodology effectively recommended the shortest path for obtaining the required action figure and reduced the waiting time at the convenience store.

1. Introduction

Ubiquitous computing is a concept in software engineering and computer science in which computing is performed at any location. As an application of ubiquitous computing in the manufacturing sector, ubiquitous manufacturing (UbiM) features an environment in which manufacturing services are provided at any location. A concept similar to UbiM is cloud manufacturing (CM; [26]). Both UbiM and CM enable ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., software tools, equipment, and manufacturing capabilities). However, in contrast with CM, UbiMemphasizes the mobility and dispersion of manufacturing resources and users.

In general, manufacturing a product ubiquitously is impossible. Previously, UbiM implied that products could be supplied ubiquitously. Some advanced manufacturing technologies, such as lean manufacturing [4], CM, manufacturing grids[15], global manufacturing [15], virtual manufacturing [21,7], agile manufacturing [16], Internet manufacturing [17], and particularly additive manufacturing (AdM; [19]) have increased UbiM opportunities. An AdM network can be used to transfer the three-dimensional (3D) model of a product (in .STL or .OBJ file format) to a 3D printer at any locationand any time over the Internet, at which point the product isbuilt layerbylayer. At the end of the manufacturing process, excess soft resin is cleaned using a chemical bath [5]. Thus, manufacturing a product ubiquitously has become possible. Developments in AdM have enabled printing extremely complex 3D models. Various methodologies, such asthat developed by Ding et al. [13], have been proposed for generating deposition paths and arcs for such products. Keating and Oxman [18] reconfigured a 6-axis robotic arm into an integrated platform for 3D printing, milling, and sculpting and proposed the concept of "compound fabrication."

This study established a UbiM network system, in which a customer requests that a product be manufactured at a 3D output locationand arrives atthe 3D output location for the just in time (JIT; [8]) manufacturing of the requested product. UbiM network systems are used to manufacture action figures of popular cartoon or movie characters. The business feasibility of using a 3D printer to manufacture action figures was mentioned by Berman [5] and has been successfully demonstrated [10]. Information companies, 3D photo studios, supermarket chains, and other shops provide (Table 1) limited services for the printing of 3D action figures. In addition, by mass-producing action figures, 3D printing service providers such as the Shenzhen Xin Ju Xin Toy Design Company [24] have contradicted the conventional belief that 3D printers can be used only for small-scale trial production. However, most of the existing service providers have a single 3D output location;a systematic UbiM network remains undeveloped.

As shown in Table 1, some companies have substantial waiting periods for receiving desired action figures. Such waiting is worthwhile if 3D printing enables customers to receive an action figure that they want as soon as possible, because even the largest

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Table 1
Examples of 3D printing service providers.

Service provider	Region	Service items	Size of action figure	Price (USD)	Required time	Reference
Asda [1]	UK	Scan & print	Unknown	45～	A week afterward	http://www.3D-printing.net/content/asda-launching-3D-printing-service-tomorrow
Chih-Mao information	Taiwan	Print; Scan & print	Height: 10 cm	32–39 /h	4.83 h	http://www.cmic.com.tw/Production_process.aspx
EGO3D	Taiwan	Scan & print	13–15 cm	415	1–2 weeks	http://www.ego3d.com.tw/price.html
Shenzhen Xin Ju Xin Toy Design Co.	China	Print	Unknown	2–20	8–15 days	http://szjxsy.en.alibaba.com/product/60239779940-212431068/3d_printing_anime_action_figure.html#!

toy makers do not stock all types of action figure. In addition, transporting an action figure from an overseas toy maker to a customer's location may involvea longer waiting time. After the ordered action figure is printed, the customer visits the 3D output location and collects the action figure. Presently, the 3D output location may be located a considerable distance from the customer's location. Therefore, for overcoming this problem, this study proposed a UbiM network system. The customer can be guided to the nearest 3D output location to reduce travel time, a procedure called static UbiM. In another situation [6], dynamic UbiM was used for further elaborating the effectiveness of UbiM network systems. In this study's procedure, a customer receives directions for obtaining a pre ordered action figure from a preferred 3D output location while traveling according to the following objectives:

(1) The customer should promptly leave for the 3D output location.
(2) The 3D output location should be located near the customer's route.
(3) When the customer arrives at the 3D output location, the requested action figure should be ready. In other words, the customer's waiting time at the 3D output location should be minimal.

For achieving these objectives, the proposed methodology designated a chain of convenience stores to be the 3D output locations; the stores are suitable for the following reasons:

(1) Some regions contain a high concentration of convenience stores that provide nearly identical services. For instance, a 2-km^2 region in the Zhongzheng District of Taipei City in Taiwan (Fig. 1) contains 36 convenience stores of the same chain.
(2) Most convenience stores provide printing services, which could serve as a basis for 3D printing services.
(3) Convenience store chains in Taiwan regularly introduce promotional campaigns that allow customers to exchange points, accumulated after a fixed amount of purchases, for an action figure.

The remainder of the paper is organized as follows: Section 2 presents a literature review of 3D printing. Section 3 describes the architecture and process flow of UbiM network systems. Section 4 presents a fuzzy integer-nonlinear programming (FINLP) model for solving the JIT output location and path problems. For solving the FINLP problems for static UbiM and dynamic UbiM cases, two modified fuzzy Dijkstra algorithms were proposed. In addition, two cases were used to illustrate the applicability of the proposed methodology. Section 5 presents a comparison of the performance of the proposed methodology with that of an existing method. Finally, Section 6 concludes the paper.

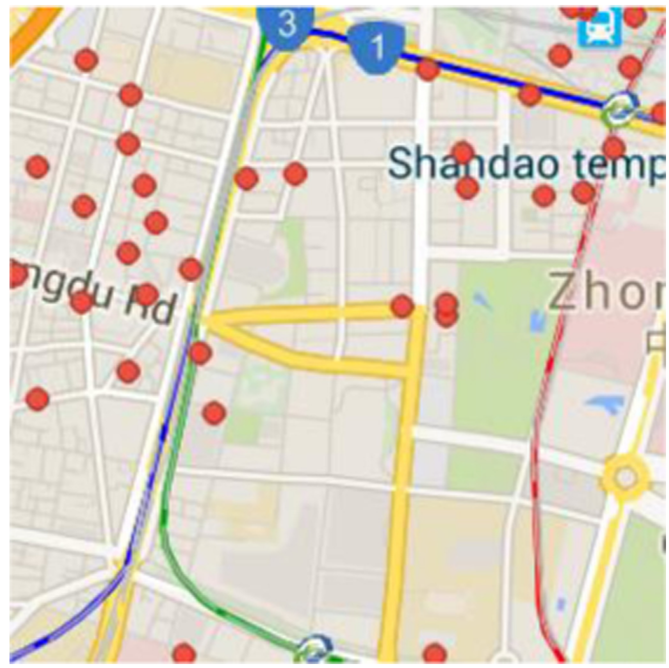

Fig. 1. Distribution of convenience stores in a 2-km^2 region.

2. 3D printing

2.1. Platforms

3D printing can be seamlessly integrated with CAD/CAM operations [5]. Therefore, the existing CAD/CAM software vendors are typically the pioneers in this field. For example, Autodesk recently developed an open 3D printing platform named Spark [3] on which application program interfaces (APIs) are provided for each stage of 3D printing. Consequently, 3D printing functionality can be quickly added to an application. By using Spark, a customer can design and even optimize a 3D model that can be printed by a specific 3D printer.

There are also websites acting as hubs for gathering 3D models from volunteers worldwide. For example, My Mini Factory test prints an uploaded 3D model before it is publicized [22]. Through its online catalog, shapeways shows the 3D models it has collected for printing and purchasing, thus providing the company with a 3.5% commission from the designer of each 3D model printed or sold. Equipped with more than 100 3D printers of various sizes, i. materialise can be used to print 3D models uploaded by customers or passed from websites that provide 3D printing services but do not have printers [14]. APIs are provided for connecting a service website to i.materialise, in addition to third-party logistics that directly ship the printed 3D model to the service website's customer.

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