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Technical Paper

Data-driven cost estimation for additive manufacturing in cybermanufacturing

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ABSTRACT

Cybermanufacturing is a new paradigm that both manufacturing software and hardware tools are seamlessly integrated by enabling information infrastructure and are accessed as services in cyberspace. This paradigm encourages tool sharing and reuse thus can reduce cost and time in product realization. In this research, a new cost estimation framework is developed based on big data analytics tools so that the manufacturing cost associated with a new job can be estimated based on the similar ones in the past. Manufacturers can use this cost analytics service in their job bidding process, which is currently ad hoc and subjective in industry practice. The new framework is implemented and demonstrated for additive manufacturing, where the similarities of 3D geometry of parts and printing processes are established by identifying relevant features. Machine learning algorithms for dynamic clustering, LASSO and elastic net regressions are applied to feature vectors to predict the cost based on historical data.

1. Introduction

Competition in manufacturing industry calls for the transformation from traditional cost reduction in mass production to value proposition in customer-oriented product development. The driving force is the development of technologies to enable faster and seamless information sharing between manufacturers within supply chains as well as customers, government, and other stakeholders. Information flow becomes a critical element of supply chain in addition to materials and energy flows. With the support of information infrastructure, manufacturers will be able to become more agile in acquiring information, internally (e.g. cost of production, inventory) or externally (e.g. customer satisfaction, market trends). With such information, more intelligent and timely decisions can be made to ensure the success in global competition.

Nevertheless, the three major challenges of time, cost, and quality in production still remain for small and medium sized manufacturers (SMEs), who usually do not have resources to implement and host the latest industry information technologies to support informed decision making. A new term of cybermanufacturing was recently formed. Yet, there is no clear and consistent definition about what it is. It has been interpreted as Internet enabled process control [1], data driven operation enabled by cyber-physical systems [2], fully networked manufacturing systems [3], or loosely cloud manufacturing [4], cloud based design and manufacturing, and industry 4.0. In a more rigorous way, cybermanufacturing can be defined as a new paradigm that both manufacturing software and hardware tools are seamlessly integrated by enabling information infrastructure and are accessed as services in cyberspace. Simply speaking, cybermanufacturing is the new paradigm that helps realize manufacturing as services.

In this new federated paradigm, users may use the functions of software tools via remote access and remote procedure call in a networked environment, as illustrated in Fig. 1. Software tools include computer-aided design (CAD) for geometric modeling, finite-element analysis (FEA) that predicts the physical effects of manufacturing processes, data storage and data analytics tools which archive and analyze the data collected from both sensors and simulations and assist decision making, and others. Hardware such as machines and printers for various manufacturing processes can also be plugged in the cyberspace of enterprise networks and provide services in the global network. A client can request products to be designed and manufactured through Apps or cybermanufacturing gateway. Software and hardware tools also request services from each other transparent to clients. The exchanged digital data between tools include CAD files, simulation inputs and outputs, G-code for machine tool paths, sensor data collected from machines, etc. The major elements of enabling information infrastructure for this service-oriented cybermanufacturing paradigm include easy-to-access software and hardware tools as services, service catalog

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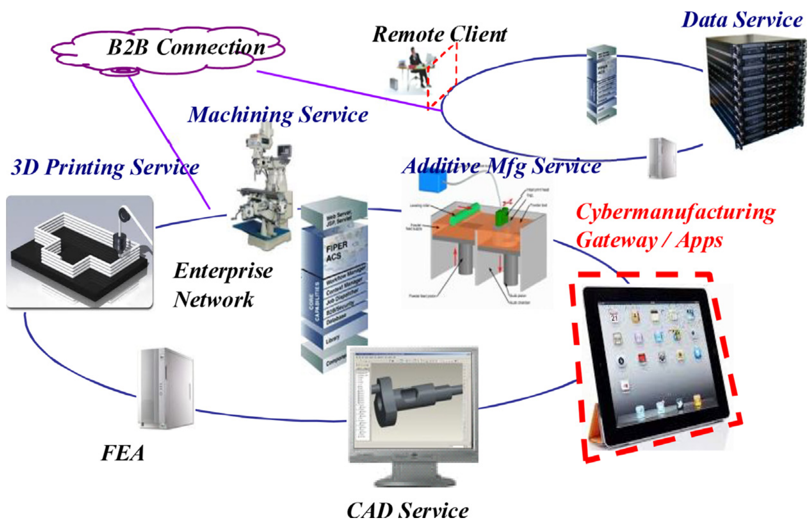

Fig. 1. Service-oriented information infrastructure for cybermanufacturing.

and indexing that provide search capability, and interoperable protocols and middleware platform to enable the integration [5–7]. The federation is achieved by service-oriented architecture or cloud computing [8,9]. Note that the concept of computing as service or resource virtualization is not new and has been referred to as utility computing since 1960s [10]. Recent software implementations specifically for engineering applications include FIPER [8] and DOME [11]. Commonly used engineering software packages also adopted some of these features [12]. With the support of these tools, a subscription based architecture could be a viable solution for SMEs so that they can subscribe hardware and software services as needed without the need of hosting and maintaining all in-house.

One critically needed service for SMEs is cost analysis, where SMEs can have quick and accurate predictions of production costs when they are bidding new jobs. Current industry practice is subjective and ad-hoc with high risks. For instance, in the injection molding industry, an average molder has over 700 unique parts to mold [13]. Yet there is no universally accepted way to bid molds. Many companies that operate as small job shops do not have the resources to develop a systematic way to bid the molds. The ad-hoc cost estimation procedure is dependent on the competency and experience of the person who does the bid. This carries significant risks for SMEs, since each bid is critical to those companies. An unrealistic low bidding price would cost the company (instead of bringing profits), whereas an unnecessary high bidding price could lead to the loss of the bid. To minimize such risks, a systematic method for automated and accurate cost estimation of injection molds is needed. Similarly, for low-volume production such as additive manufacturing or three-dimensional (3D) printing, customers now can submit jobs online and request printing services from many service providers, including UPS [14]. Existing 3D printing cost estimation is primarily based on the hardware properties of the products by manufacturers, such as the price of the printer, the size of the part, the amount of materials used, as well as planning labor cost [15,16]. These cost estimation approaches are also heavily dependent on the bidder's experiences.

In this paper, we propose a data-driven approach to reduce the subjectivity of cost estimation process, given that large amounts of product and production related data are readily available as database and information technologies advance. The predictive data analytics for manufacturing cost estimation, or cost analytics, can be provided as services in a cybermanufacturing environment to benefit both small and large manufacturers. The proposed

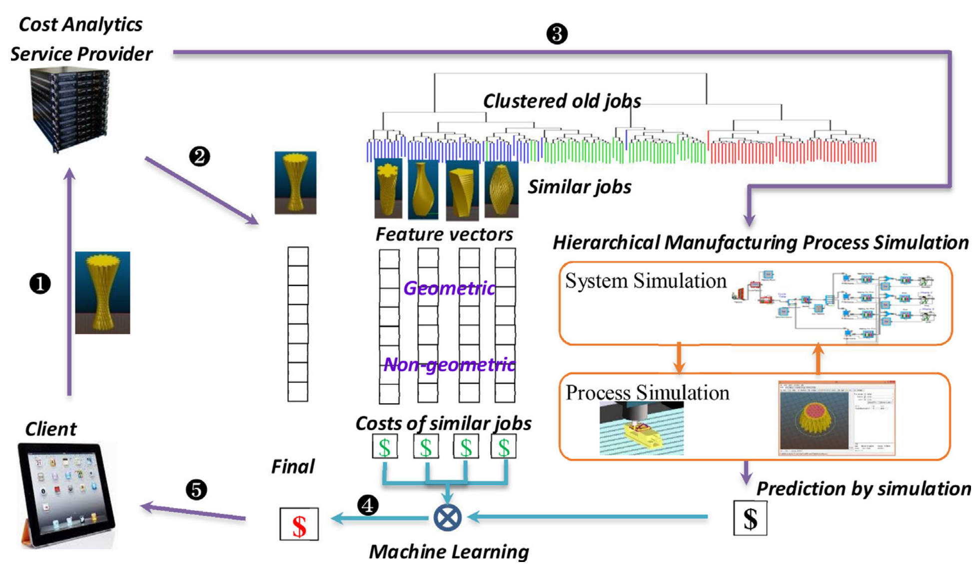

Fig. 2. The cost analytics service framework in cybermanufacturing based on geometry and process similarities.