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Machine availability monitoring and machining process planning towards Cloud manufacturing

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ABSTRACT

Cloud manufacturing as a trend of future manufacturing would provide cost-effective, flexible and scalable solutions to companies by sharing manufacturing resources as services with lower support and maintenance costs. Targeting the Cloud manufacturing, the objective of this research is to develop an Internet- and Web-based service-oriented system for machine availability monitoring and process planning. Particularly, this paper proposes a tiered system architecture and introduces IEC 61499 function blocks for prototype implementation. By connecting to a Wise-ShopFloor framework, it enables real-time machine availability and execution status monitoring during metal-cutting operations, both locally or remotely. The closed-loop information flow makes process planning and monitoring feasible services for the Cloud manufacturing.

1. Introduction

Today, the global market is characterised by turbulent demands for highly customised products. Customers are increasingly demanding for higher quality products at low cost with quick delivery, and for shorter times between successive product generations. Cooperation among different companies becomes product-specific, customer-centric and dynamic. Manufacturing jobs are diversified and urgent. Moreover, outsourcing, joint ventures, and cross-border collaborations have led to a shop-floor environment geographically distributed across corporate and national boundaries. Moreover, the uncertainties of today's machining operations make this distributed environment further complicated. Companies and decision systems must be more flexible and adaptive to unplanned deviations on turbulent shop floors where metal-cutting processes should be adjusted dynamically to the changes. It is evident that factories of the future must contain smart decision modules that can fine-tune runtime operations adaptively to achieve specified production objectives. However, today's manufacturing systems still exhibit various limitations, especially in flexibility and adaptability.

On the other hand, modern manufacturing industries have shown clear trends in recent years – away from long standing and well-established products and relevant production that have been stable over many years, away from comprehensive trusts that may cover all the processes of production, and also away from the single economic consideration of production; instead, companies increasingly focus on their core manufacturing competencies, develop and produce adaptive and customised products, enter more often into alliances for manufacturing and resource optimisation, and integrate environmental and social responsibilities into their operations. This trend will lead to an Internet- and Web-based service-oriented Cloud manufacturing in the future to overcome today's limitations in rigid system structure, standalone software usage, centralised resource utilisation, unidirectional information flow and off-line decision making.

As one of the core components of a manufacturing system, computer-aided process planning (CAPP) is desired to be responsive and adaptive to the changes in production capacity and functionality. Unfortunately, conventional CAPP systems are neither flexible nor adaptive, if applied directly to dynamic operations. Quite often, a process plan generated in advance is found unfeasible or even unusable to targeted resources, resulting in wasted time and effort spent in early process planning – a productivity drop when idle machines must wait for re-planning the remaining operations. Within the context, an adaptive approach is considered suitable and is thus proposed in this paper for dealing with the dynamic situation, e.g. job-shop machining.

Targeting the Cloud manufacturing, the objective of this research is to develop an Internet- and Web-based service-oriented system for machine availability monitoring and process planning. Particularly, this paper proposes a tiered system architecture and introduces an event-driven approach using IEC 61499 function blocks. By connecting to a Wise-ShopFloor framework, it enables real-time machine availability monitoring and machining status monitoring during metal cutting, locally or

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remotely. The closed-loop information flow makes process planning and monitoring feasible services for the Cloud manufacturing.

The remainder of the paper is organised as follows. Section 2 reviews the state of the art of the relevant research works. Section 3 introduces a new Web-DPP concept, which is extended to system architecture design in Section 4. System analysis of the Web-DPP is reported in Section 5 in form of IDEF0. The system is implemented and outlined in Section 6. In Section 7, a sample part machining is chosen to demonstrate and validate the capability of the prototype system in terms of process planning and machine availability monitoring. Finally, research contributions and future work are summarised in Section 8.

2. Literature review

The concept of Cloud manufacturing is based on cloud computing, e.g. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). It is a new-generation service-oriented approach to supporting multiple companies to deploy and manage services for manufacturing operations over the Internet. Cloud manufacturing would provide cost-effective, flexible and scalable solutions to companies by sharing complex manufacturing software tools as services with lower support and maintenance costs. The development of Cloud manufacturing includes design of four layers [1]:

- Manufacturing resource layer, such as manufacturing equipment, sensors, servers, etc.
- Manufacturing virtual service layer, in which manufacturing resources are identified, virtualised and packaged as services. Identification and communication technologies have been researched, including wireless sensor network, RFID, Internet of Things, MTConnect [2], etc.
- Global service layer, which relies on a suite of Cloud computing technologies such as PaaS to take global service computing and supporting for various demands and requirements.
- Application layer, which is the interface for users to invoke services for applications. Wise-ShopFloor [3] is such an example.

Although cloud computing has been active during the past decade, there have been no research projects on Cloud development for process planning at machine and execution control level, which is an imperative research area for developing a comprehensive Cloud manufacturing environment for factories of the future.

Process planning is commonly known as a bridge between design and manufacturing of a mechanical product. The tasks involved are generally preparatory, including process sequencing, resource (machine and cutter) selection, cutting parameter assignment, tool path planning, operation optimisation, and numerical control code generation. Process planning also relates to setup and fixture planning, closely. Computer-aided process planning (CAPP) dates back to 1960s when computers were first introduced to the field. Two decades later, more than 156 CAPP systems were reported in a literature survey [4] in 1989. Since its beginning, CAPP research has continuously attracted a large amount of interest over the past four decades. To date, a huge volume of literature has been published on this very subject. Among many others, previous research studies on CAPP include machining feature-driven approach [5], object-oriented approach [6], Petri net-based approach [7], neural network-based approach [8–10], genetic algorithm-based approach [11], constraint-based approach [12], multi-agent bidding-based approach [13], and knowledge-based approach [14,15]. In terms of specific application domains, the reported approaches, together with their variants, have been applied to process sequencing [16], cutter selection [17], cutting parameter selection [18], tool path planning [19], setup planning [20], etc. Today, machining feature-based approaches combined with artificial intelligence-based methods are the popular choices for process planners. Although the existing approaches can address the core decision-making problems involved in process planning, they are often *centralised* in decision making, *static* in system structure, and *time consuming* in computation, with many unrealistic assumptions on the availability of resources and production environment.

In terms of process planning methodologies, research efforts have recently been shifted to distributed process planning [21,22], reconfigurable process planning [23], integrated planning and scheduling [24], and energy-efficient process planning based on the capacity profile of machine tools [25,26]. Despite the naming differences, their common objective is to generate robust, flexible, precise yet adaptable process plans, effectively. Nevertheless, process planning research is facing new challenges today owing to the dynamic market and business globalisation in much more decentralised manufacturing environment than ever before. It demands for a new way of thinking in process planning that is collaborative among engineering teams and adaptive to environmental changes on manufacturing shop floors. On this front, the latest ICT technologies including the Internet, Web, Java, XML, etc. are popularly used for collaborative process planning to support a networked manufacturing environment. Within this context, a process planning system must be able to accommodate the variation and distribution of manufacturing resources and materials processing tasks, in collaboration with different process planners. In other words, it deals with how to support collaborative process planning among the planners at different places, and how to improve instantaneous communication among each other. In the work by Xu et al. [27], they put forward an idea that used computer screen-sharing technique to support a multi-user cooperation. This approach overcomes the limitation on processing resources and knowledge in the traditional narrow-sense process planning, and improves planners' collaborative work. In the same year, Java language was adopted to transfer a CAPP system to Web-based environment so that its functions and operations can be distributed to various computer systems to reduce the computational load on a single computer [28]. The distributed computing environment is based on J2EE, enabling the manufacturing processes to be planned effectively over the Internet. In the research by Qiu et al. [29], a distributed multi-user environment over the Internet was suggested. It was implemented as a Web-based system by combining an external authoring interface and Java. This system allows users carrying out manufacturability evaluation based on a pre-defined process plan. Another Internet-enabled system was reported in [30] for setup planning in machining operations using Java and Web technologies, where XML was used to transfer data and information between various manufacturing systems. Agent technology was also popularly used in collaborative process planning in recent years. A multi-agent system for distributed process planning was presented in [31]. Three autonomous agents, (i.e. Global Manager Agent, Design Agent, and Optimisation Agent) are capable of communicating with each other through XML. Hence, it enables process planning in a distributed e-manufacturing environment.

Another dimension of process planning is the adaptability of a process plan to unforeseen changes on manufacturing shop floors. Here, the dynamic changes are dubbed uncertainty, such as frequent production change, job delay, missing or broken cutters, unavailable fixtures/machines, rush orders from clients, and even the short notice of sick leave of an operator. Such dynamic characteristics of manufacturing shop floors pose an unprecedented challenge to CAPP systems. In this situation, a process plan generated in advance is often found unfeasible and