A Framework for Cloud Manufacturing Enabled Optimisation for Machining

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Abstract. Cloud Manufacturing is considered to be one of the paradigms that could revolutionize the way manufacturing has been realized in the industrial sector. Cloud Manufacturing services could be applied in most sectors of manufacturing since services can get integrated in the existing workflows. However, one of the most challenging while also most promising aspect is the reinterpretation of workflows and the creation of new workflows which could lead to more cost effective operations in the manufacturing industry. In this paper a framework for the optimization of cutting conditions in machining as part of a Cloud Manufacturing environment is presented. The aim of the framework is to provide users with an easier to use, cost efficient and well-informed solution that promotes sustainability in workshops. The main challenges, drivers and limitations in creating such an environment are discussed.

Keywords: Cloud Manufacturing, optimization, machining, CNC

1 Introduction

Cloud Computing has established a new way of using computing resources through the web. The Cloud Manufacturing paradigm has just recently been introduced [1] and is aiming to revolutionize the way manufacturing is performed in industry. Moreover, the advances in electronics have made it possible to have wirelessly interconnected sensors and microcomputers through the internet. Lately the modern industrial environment calls for optimal manufacturing, greater energy efficiency and flexibility of production lines. In this context this paper presents a framework for the optimization of manufacturing toolpaths for milling machines, based on a Cloud Manufacturing environment. The details of the structure, the interfaces and the modules of such a framework are discussed.

The remaining of this paper is organized as follows: Section 2 provides the background information on the Cloud technologies and reviews the state-of-the-art in the subject. The proposed framework structure is described in in Section 3, while in Section 4 details on the proposed framework such as interface requirements are presented. Finally, Section 5 contains concluding remarks and future work on this framework.

adfa, p. 1, 2011.

2 From Cloud Computing to Cloud Manufacturing

The way applications are structured and delivered to the clients in a Cloud Computing platform have many differences with the traditional IT approach. In Cloud Computing services can be provided through the web in a flexible scalable and on demand manner [2]. Services can be delivered in a Cloud Computing environment with three different models. Infrastructure as a Service (IaaS) provides the user access to computing resources such as computers, virtual machines storage etc. The Platform as a Service (PaaS) model provides users with computing platforms for developing their cloud application based on an IaaS framework provided and managed by the vendor. Finally Software as a Service (SaaS) is the model that customers use to gain access to applications residing on the Cloud. These applications are managed by the vendor and are made accessible to the user through thin clients or web browsers. With regards to the deployment of Cloud services this can be done in private, public or hybrid clouds, with the last being the most promising since they can combine the advantages of private and public clouds.

Similar to Cloud Computing, Cloud Manufacturing is a new paradigm for using Cloud Computing in the sector of manufacturing [1]. In addition to the usual resources used in Cloud Computing, such as networking storage and application capabilities, the Cloud Manufacturing paradigm exploits sensory networks to drive manufacturing equipment through the internet and create a cyber-physical system. In this way, a series of other services throughout the manufacturing chain can be produced.

Industry 4.0 [3] describes a framework in which modern manufacturing companies will operate using decentralized intelligence and multi-sources of information in order to create the above mentioned cyber-physical system. The main driver behind this framework comes from a series of connected devices that are connected through the Internet of Things [4].

In recent years many architectures and services have been presented in the area of Cloud Manufacturing that use the advanced capabilities of Cloud Computing to facilitate the operations in the manufacturing sector. Moreover researchers have focused on the challenges, drivers and advantages of such systems [5-8]

Wang et al. [9,10] presented a system for process planning and operation planning and control of manufacturing equipment based on standardized Function Blocks (IEC 61499 [11]). Function blocks are event-driven logical units that calculate data and event outputs using embedded algorithms based on input data and events. This technology can be used in order to bypass the G-code generation and talk directly with the controller of CNC machines. The development of a Cyber-physical as part of a Cloud manufacturing based system was presented by [12]. Wang [13] presented a Cloud based manufacturing system for availability monitoring and process planning

In their research, Wang and Xu [14] presented a service-oriented, interoperable Cloud Manufacturing system. A three layer Cloud Manufacturing structure was proposed that handles the Cloud Manufacturing services, the Services provider and the Cloud Manufacturing service queries. In further research [15] they discussed the sustainability aspects of Cloud Manufacturing. The way Cloud Computing could aid the manufacturing sector and create a Cloud Manufacturing environment was presented by Xu [16].

Studies have also started to focus on the development of services that operate as part of a Cloud Manufacturing environment. Anbalagan et al. [17] presented a feature recognition system that could collaborate with and adaptive process planning system and that could be based on a Cloud environment. Tapoglou et al. [18] presented a system for the calculation of optimal cutting conditions and toolpath creation that can work with a Cloud Manufacturing system.

3 Framework Structure

This work introduces a new framework for the calculation of the optimum cutting conditions and toolpaths as part of a Cloud Manufacturing based environment. The proposed framework uses a two layer optimization in order to calculate the optimum cutting parameters and tune them in an online manner. The optimization framework would be hosted in a hybrid Cloud for protecting the IP of the designs and the manufacturing knowledge while at the same time allowing access to some information to the general public. The entry point for the system is the optimization module through which the user gets access to a series of services that can be connected to the module. The architecture of the system is presented in Fig. 1.

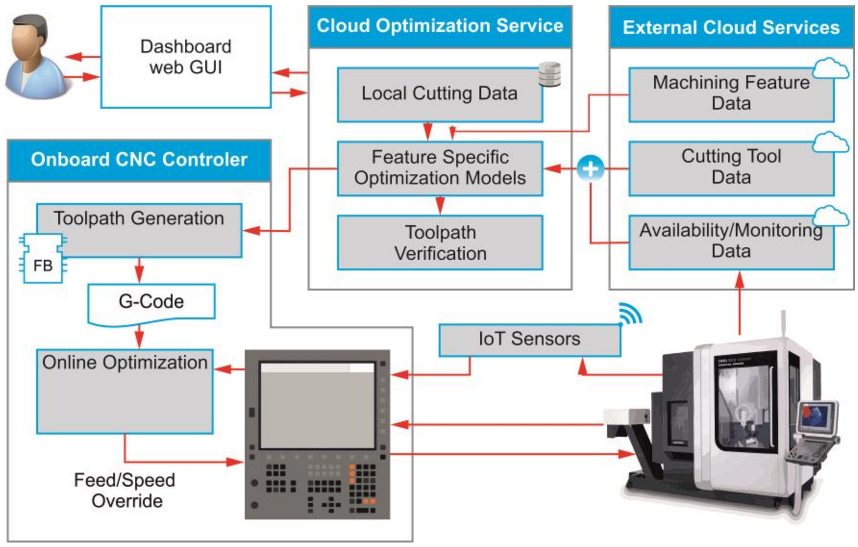

Fig. 1. The architecture of the proposed system

The first layer of the optimization is realized on the Cloud. This layer is mainly responsible for the calculation of the optimum toolpath parameters as well as feeds and speeds for machining the part's features. The data required for this operation are drawn from multiple external sources and reflect the status of the workshop, the machine tools and cutting tools. Moreover recommendations regarding the cutting tool parameters as well as user preferences are taken into account in the optimization process, to deliver an optimal result to the end user. After the optimization, the optimal parameters are verified through a toolpath verification module and then fed to the machine tool controller.

In the second layer the optimal toolpath parameters and feeds and speeds are fed into the onboard software for creating the machining code for realizing the part. During the execution of the machining code a series of embedded and external sensors give feedback information to the onboard optimization module which in turn fine-tunes the cutting parameters to adapt to the dynamic characteristics of the system. The dynamic data monitored are also sent back to the Cloud so that the information can be used for the adjustment of the cutting conditions for later use.

By using a Cloud based approach the propose architecture is able the latest information with regards to best practices taken from online sources and local centralized databases and take well informed decisions in the workshop environment.

4 Functionality and Interfaces

In this section the interfaces with the different modules that provide information to the optimization module are discussed. Moreover, the functionality of the two layers of the optimization module is presented.

4.1 Machining feature information

An interface protocol that describes the geometrical characteristics of the part that is going to be machined is needed. STEP protocols provide such information that are widely adopted by most CAD software. The STEP application protocol 240 [19] could serve as a good interface between the optimization module and the geometry providers. The AP240 STEP format provides the machining information details as well as the process planning details for machining the part [20]. The geometrical data regarding the parts are pulled by the optimization system through XML files. The data describing the geometrical features of the parts can be stored on the private Cloud section of the hybrid Cloud if the part is created with in-house design tools or they can be stored on the public section with the data being encrypted to preserve the IP. In the latter case the design details can be shared with users that have viewing/editing rights.

4.2 Availability/Monitoring

In order to be able to make a well-informed decision, the optimization module needs the latest information on the availability of machine tools and cutting tools. For getting access to the latest information, a universally accepted protocol such as MT Connect [21] should be used. The data collected through the availability module would allow the selection of the most appropriate tools and cutting conditions during the optimization process. Most modern CNC machines come with a MT Connect agent embedded so data regarding the status of the tools can be drawn. This protocol could also be used by additional sensors installed on CNC machines such as current measurement sensors as that could be used in the availability monitoring of legacy machines like the ones presented in [22, 23].

4.3 Cutting Tool Data

Traditionally cutting conditions are decided through tool manufacturer recommendations and operators experience. To get the manufacturers recommendations into consideration the optimization module must have connections to the tool libraries of the manufacturers. ISO 13399 [24] presented such a framework for tool data representation. Adveon [25] and NovoSphere [26] are two of the services already existing in this field that can provide the cutting condition starting values to the optimization module. Through such interfaces the normal operating windows for the cutting tools can be obtained thus allowing the optimization module to select cutting conditions ensuring increased productivity and eco-friendliness [28].

4.4 Cloud Based Optimization

In order to select the optimum conditions for machining a series of steps must be realized. The first step in the realization of the optimization is the retrieval of the process plan through the machining feature interface. Every machining feature has to have a corresponding optimization model, similar to the one presented in [18], for the calculation of the optimal cutting condition that takes into consideration the special requirements of each machining feature. The next step is the retrieval of the tools available on the machine that is selected to realize the machining process. The cutting parameter recommendations are retrieved then through the cutting tool data interface. The recommended cutting data are combined with the local cutting data stored on a private database on the cloud optimization module in order to include best practices from the tool manufacturer and the user of the system. In the optimization core, multi objective algorithms calculate the optimization problem. The objectives taken into consideration include the minimization of production cost, the minimization of energy consumption and the maximization of the throughput. The constraints that need to be taken into consideration include achieving the required tolerances, tool wear limits and respecting the machine and tools limits. After the optimization has taken place, the solution can be verified through the use of simulation software to check the validity of the proposed solution. Then the cutting parameters can be broadcasted to the machine tool. This layer of optimization does not calculate the exact toolpaths; instead it calculates the best cutting parameters for executing the machining. This way the information broadcasted to the machine are kept to a minimum. By keeping the broadcasted information to a minimum there is a smaller risk of compromising and corrupting the data.

4.5 Onboard Optimization

The second layer of the optimization is the fine tuning of the cutting conditions. After the optimal cutting conditions are fed into the machine, IEC 61499 [27] function blocks are used to create the machining code for machining a specific feature with the optimal cutting conditions. After the creation of the machining code the machining process can start. During the machining process embedded and external sensors give information regarding the machining process to the controller. Most of the signals to the controller are used by the controller for checking the status of the machine and executing the command movements. Some of these signals can also be used to diagnose the cutting process and further optimize it. In more detail sensors measuring the power needed on the main spindle and the axis drives can be combined to give information regarding the cutting power required for machining. Accelerometers fitted on the spindle could give information regarding vibrations on the spindle. The online optimization module is responsible for adapting the cutting conditions to eliminate unfavorable cutting conditions while at the same time maximizing the throughput of manufacturing and achieving the required tolerances. A multi-objective model predictive control is used to calculate the best feeds and speeds according to the sensed status of the machine. By using this layer the cutting conditions are fine-tuned according to the dynamic characteristics of the specific case.

5 Conclusions and Future work

This paper presented a two layer framework for the optimization of cutting conditions in CNC milling machines would run as part of a Cloud Manufacturing environment. The requirements regarding the interfaces of such an environment were introduced as well as the link to existing standards. The functionality of the two layers of optimization were also discussed. Cloud based manufacturing systems are starting to get adopted in the industrial sector but some challenges need to be addressed before they are fully integrated in their workflows. Apart from the interfacing issues regarding different subsystems, the security and IP issues of Cloud based solutions need to be resolved. By using a hybrid Cloud structure and embedding knowledge in the controllers, the proposed framework presents a solution towards solving these two issues. A privately stored database is used to store the knowledge of the user of the system thus protecting the knowhow from the public. By using a two-layer architecture, the system can generate a generic optimal solution for machining a specific geometry while at the second layer the fine tuning of the cutting parameters according to the dynamic characteristics of the system can be achieved. The next steps in the development of the proposed architecture are the incorporation of the optimization modules in the framework and construction of a case study that will show the benefits of using such a system. Moreover, the inclusion of additional interfaces and services in this architecture is needed to get an all-around solution for manufacturing.

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