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Cloud Manufacturing Framework for Smart Monitoring of Machining

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Abstract

A cloud manufacturing framework is developed to realize on-line smart process monitoring in the machining of difficult-to-machine materials. The computing and service resources in the cloud are connected to the machine tool realising a cyber-physical system. A multi-sensor system is employed to collect in real time multiple sensor signals during machining. Advanced signal processing and cognitive decision making activities are assigned to the cloud server to exploit the cloud capabilities according to a service oriented approach. The cloud service offers knowledge-based diagnosis on tool conditions through cognitive paradigms able to learn from sensorial data. Based on the cloud diagnosis, the local server decides on the corrective action to be taken and sends the proper command to the machine tool control.

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Keywords: Cloud Manufacturing; Machining; Sensor monitoring; Cyber Physical System

1. Introduction

The Cloud Manufacturing paradigm is one of the most innovative Key Enabling Technologies (KETs) for modern manufacturing industry and is claiming increasing attention in manufacturing research [1-5]. Cloud technologies provide an environment to connect and share distributed manufacturing resources including knowledge, computing and software tools, as well as physical resources via the Internet networking infrastructure, and can be employed for a wide range of manufacturing applications such as process planning, machine tool monitoring, process monitoring and control [2-11].

In this paper, a cloud manufacturing framework is developed to realize on-line smart process monitoring in the machining of difficult-to-machine materials. The framework is configured with particular reference to tool condition monitoring, which is a critical issue when cutting low machinability materials, due to the rapid development of tool wear and the unpredictable occurrence of catastrophic tool failure [12-14].

The development of smart monitoring procedures can significantly increase productivity and reduce tool costs, optimizing tool life by implementing condition-based tool replacement strategies (i.e. by replacing tools only when they are close to end of life) instead of conservative time-based tool replacement strategies (in which the tool is replaced after a predetermined time independently of its real wear conditions) and they can help reduce machine and workpiece damage risk by allowing fast reaction when a tool breakage occurs.

This would allow to enhance the performance of manufacturing processes in the perspective of zero defect manufacturing and to support the reliable automation of manufacturing systems via smart system adaptation [13,15].

The implementation of a cloud manufacturing framework represents a remarkable advancement for smart monitoring of machining, allowing to exploit the cloud capabilities in order to offer real time diagnosis on tool conditions according to a service oriented approach. Introducing sensors and networked communication into the factory strongly supports smart in-process diagnosis as well as the timely activation of adaptive actions based on actual process conditions [16]. These actions include human interventions and proper commands directly fed to the machine tool numerical control, improving the robustness and adaptability of processes and systems.

According to the proposed cloud manufacturing based

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monitoring framework, the computing and service resources in the cloud are connected to the physical production devices (i.e. machine tools, sensor systems) realising a complex cyber-physical system (CPS) [17-19].

The cloud server receives the pre-processed sensorial data acquired by a multiple sensor system mounted on the machine tool and provides services consisting in the diagnosis on tool conditions related to the detection of tool failure events through a knowledge based approach as well as to the estimation of tool life through a neural network (NN) based cognitive paradigm using features extracted from the acquired sensorial data [13].

The diagnosis on tool conditions benefits from the cloud infrastructure in terms of enhanced computational capability, which improves the execution efficiency of the diagnosis and enables more robust decision-making due to large information and knowledge sharing available in the cloud [16].

Based on the diagnosis on tool conditions provided by the cloud service, it is possible to locally select and automatically activate proper actions at factory level, such as emergency process halting, tool replacement or parameters change.

2. Cloud manufacturing framework for smart monitoring of machining

The cloud manufacturing framework developed to realize on-line smart process monitoring during machining of difficult-to-machine materials is based on the architecture shown in Fig. 1. The computing and service resources in the cloud are connected to the physical resources (machine tool, sensor system) realising a complex cyber-physical system, which can be defined as a "physical and engineered system whose operations are monitored, coordinated, controlled and integrated by a computing and communication core" [21].

The cloud manufacturing architecture is structured in three layers corresponding to:

- Physical resources
- Local server
- Cloud server

This structure allows to share the computational effort between different resources, which can be geographically distributed and managed by diverse actors.

The physical resources and the local server are both included in the Factory Network, representing the hardware and software resources available within the production system. On the other hand, the cloud service is internet based, and can be potentially connected inside the boundary of the manufacturing company (private cloud) or outside that boundary (public cloud, requiring higher protection of data). Different methods can be adopted to connect machines, local server and provider cloud, and they must be selected based on stability, speed, distance coverage and security. Within the factory environment, Local Area Network (LAN) is preferable to Wi-Fi and Bluetooth.

By examining the three-layer structure of the proposed cloud manufacturing architecture, at the physical level a multi-sensor system (e.g. based on force, acoustic emission and vibration sensors) is mounted on the CNC machine tool.

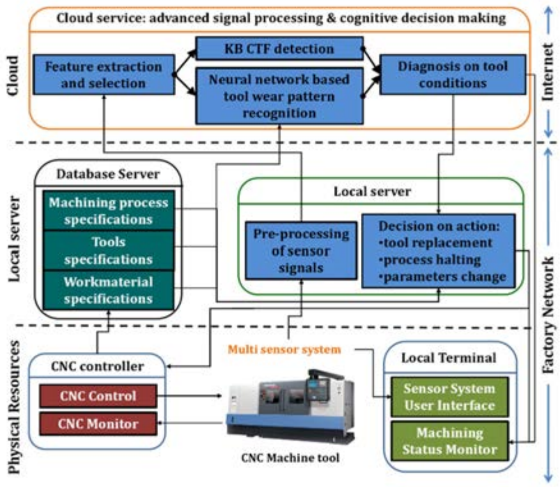

Fig. 1. Architecture of the cloud-based cyber physical system for smart monitoring of machining processes

The system is employed to collect in real time during machining multiple sensor signals that contain relevant information to use as input for the diagnosis on tool conditions.

The computing tasks related to sensor signal pre-processing are assigned to the local server. To support high computing power, the local machine works as data buffer and pre-processes the data into stand-alone data packages (sensor signal segments) which are sent to the cloud over the network [16].

The cloud computing capability is employed to rapidly perform on-line diagnostic tasks, and the potentially huge cloud database is used to maintain and share relevant information and knowledge that can support further cloud services.

The cloud server receives the pre-processed sensor signal segments, carries out the extraction of relevant signal features and performs the required diagnosis on tool conditions, detecting faults such as catastrophic tool failure through a knowledge based approach, as well as estimating consumed tool life through cognitive pattern recognition paradigms. After the computing task is completed, the cloud sends back the diagnostic output to the local server, which utilises the diagnosis result as input and reference for decision making on corrective actions. Based on the cloud diagnosis on tool conditions, the local server may select actions such as tool replacement, process halting or parameters change, and send the necessary commands directly to the CNC machine tool control. Any corrective action is displayed on the local terminal for visualization by the operator, and proper warning is displayed in case human intervention is required.

3. Physical resources: multi-sensor monitoring system

At the physical layer (Fig. 1), the CNC machine tool employed to perform the machining process must be equipped with a multi-sensor system to collect in real time various sensor signals containing valuable information on process conditions. Reliable sensor monitoring of machining processes requires the employment of a multiple sensor system to overcome the limitations of a single sensor and to realize the sensor fusion