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# Machine Availability Monitoring for adaptive holistic scheduling: A conceptual framework for mass customization

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**Abstract**

Although the market started expressing the need for high product variety three decades ago, manufacturing systems have not kept the pace with these social and economic developments. Modern industrial shop-floors are highly affected by the ever-increasing product variety and volatile market demands introduced by the currently established mass customization paradigm. The increasing complexity and high unpredictability in manufacturing activities require immediate reactions to emerging disturbances, such us reducing bottlenecks, and avoiding brake-downs and idleness of critical equipment in order to increase productivity and therefore, the company's competitiveness. The framework proposed in this research work includes machine monitoring techniques for the near real-time identification of machine status, in order to allow a predictive maintenance engine to diminish machine tool failures. Moreover, an adaptive short-term scheduling mechanism is employed, using monitoring data for the refinement of production schedules based on the current and future conditions of the shop-floor. Data acquired from a multi-sensory pilot installation together with information directly retrieved from the machine tool's controller are fused and comprise the input to subsequent software modules. The monitoring module is described, which analyses sensory data during the machine operation, as well as the Adaptive Scheduling Engine that dispatches schedules and refines future schedules based on awareness regarding machine availability. The software architecture and hardware setups are described and comprise the roadmap for the framework development. A possible application of the framework is described in the context of a European SME manufacturer.



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## 1. Introduction

In today's modern and competitive industrial society, production costs and lead time are of crucial significance for companies, especially in the mass production and mass customization domain. Unpredictable machine life and premature machine failures are major problems that must be dealt with in everyday industrial practice. Nevertheless, machine utilization must be kept in optimal levels in order to maintain productivity and achieve capital depreciation. Machine estimated useful life, utilization, cost and residual value are some of the main factors to be considered in calculating depreciation [1]. Prognostics on machine or process breakdowns and products' life expectancy estimation aim towards optimal machine utilization. Moreover, continuous monitoring, assessment and prediction of a product's performance could also enable a holistic product life-cycle management in which products are monitored, assessed and improved throughout their life-cycle. Finally, another key factor affecting mass customization is flexibility [2]. The flexibility of a manufacturing system is determined by its sensitivity to change. Changes including the rapid introduction of new products, abrupt changes in product demand and mix, and more frequent modifications to existing products create problems capable to be alleviated by a high volume, operational and / or product flexibility [3]. Increased flexibility consequently provides a manufacturing system with a series of principal advantages. To tackle these issues, the presented research work aims at providing a monitoring framework for machine status identification and prediction, so that activities like process planning and scheduling become aware and adaptive. In of a CNC milling machine and



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software implementation for results visualization in a friendly user interface on a Cloud service.

## 2. State of the art

In the field of machine availability monitoring, the authors in [4] proposed two methods for predicting machinery damage, namely the recurrent neural networks (RNNs) and the neuro-fuzzy (NF) systems for time-series analysis. Through comparison by testing them in three test cases of a worn, a chipped and a cracked gear, RNNs performed better in forecasting accuracy. Approaching the process monitoring, the authors in [5] proposed to synthesize the state variable estimates determined by different sensors and corresponding process models, through a well-trained neural network. In a recent review study the support machine vector (SVM) is presented as a promising method having an excellent performance and high accuracy in machine condition monitoring and diagnosis [6]. A new version of support machine vector named fuzzy support vector is presented by [7]. The method combines the triangular fuzzy theory with modified support machine vector. A hybrid method is presented in [8] which includes sweeping filters and tooth rotation energy estimation (TREE). A real time analysis of frequency components of the spindle signal of a milling machine provided a robust and reliable monitoring system able to identify tool breakage. A new machine condition monitoring method based on a stochastic Hidden Markov model (HMM) is presented in [9][9]. Using the HMM, not only was the precise detection of defect achieved, but also the correct identification of defect type was possible. Moreover, the use of regression trees technology and time series in order to predict the future condition of the machine is proposed by [10]. The main idea is that the embedding dimension is estimated at first in order to predict the next value, determining accordingly the available observations. In [11], an aircraft air conditioning is used as a case study in order to forecast future data points and to prevent unscheduled maintenance. The proposed method includes decision trees to find patterns from past data and a genetic algorithm to find features of the time series evaluated by the decision trees. In [12], a system was reported for setup planning in machining operations using Java and Web technologies, where XML was used to transfer data and information between various manufacturing systems. Wang et al., recently proposed to use enriched machining features and function blocks to handle the uncertainty [13][14]. The goal is to generate detailed and adaptive operation plans at runtime by CNC controllers to best utilize the capability of the available machines. In [15], an improved hybrid forecasting model, namely NARX-ARMA for machine state forecasting based on vibration data is proposed. The plan and control of a distant shop floor's operations are based on runtime information from the shop floor, enabled by a Web-based integrated sensor-driven e-Shop Floor (Wise-Shop Floor) framework targeting distributed yet collaborative manufacturing environments [16]. In [17], Sokolowski deals with some specific aspects of Fuzzy Logic (FL) system implementation in machine tool and cutting process monitoring. The main scope of his research was to work out a cutting tool wear monitoring strategy which makes possible for reaching independence of the wear symptoms from the cutting conditions. Dealing with in-process monitoring and fault diagnosis of machining operations Jun, et al. [18] present a spindle-based dynamometer as a sensor to monitor a machining operation. Moreover, another approach for machinery damage is an agent-based diagnostic concept developed in [19] which includes diagnosis of unknown process behavior using self-organizing-maps and watershed transformations. The concept was transferred to industry through chemical industrial processes. According to adaptive scheduling there are several methods and approaches. A novel integrated approach has been presented which enables a dynamic scheduling of maintenance measures within complex production systems in [20]. A framework is described in [21] for understanding rescheduling strategies, policies, and methods. Viera, et al., demonstrate how the rescheduling affects the performance of a manufacturing system. Considering the problem rising from static scheduling, a dynamic scheduling problem was designed by Chryssolouris, et al. in [22] to closely reflect a real job shop scheduling environment. Moreover, another approach in which can be based the adaptive scheduling is described in [23]. A hybrid genetic algorithm which can speed up the optimization of nearly every evaluation criteria in a job shop scheduling. The main advantage of this method is the small randomness and the managed search in order to find better solutions in shorter time.

The work reported in this paper focuses on the development of a framework machine monitoring that retrieves real time information and constitutes scheduling and other production support systems adaptive to change. A CNC milling machine incapable to expose monitoring information directly was chosen specifically for that purpose, to demonstrate the ability of the method to accommodate outdated equipment and closed-architecture systems. Time series analysis of the gathered information is carried out through models utilized by a prediction engine. An adaptive scheduling engine, including maintenance planning is described and finally a software tool offered as a cloud service with user friendly interfaces is implemented for data entry and visualization of the results.

## 3. Architecture of monitoring system

This paper proposes a method in which main scheduling decisions could be determined based on exploiting information from the machine in near-real time machine condition monitoring. Real-time monitoring provides the manufacturing system with the capability to prevent errors and to propose alternative methods of scheduling. To accomplish these, this framework is based on five main steps (Figure 1):

- Machine Monitoring and Data Acquisition
- Data Preparation & Diagnostics Engine
- Prediction Engine
- Visualization of Results and Actions
- Maintenance planning & Adaptive scheduling of the system