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Surface Finish Monitoring in Taper Turning CNC Using Artificial Neural Network and Multiple Regression Methods

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Abstract

On-line monitoring systems eliminate the need for post-process evaluation, reduce production time and costs, and enhance automation of the process. The cutting forces, mechanical vibration and emission acoustic signals obtained using dynamometer, accelerometer, and acoustic emission sensors respectively have been extensively used to monitor several aspects of the cutting processes in automated machining operations. Notwithstanding, determining the optimum selection of on-line signals is crucial to enhancing system optimization requiring a low computational load yet effective prediction of cutting process parameters. This study assess the contribution of three types of signals for the on-line monitoring and diagnosis of the surface finish (*Ra*) in automated taper turning operations. Systems design were based on predictive models obtained from regression analysis and artificial neural networks, involving numerical parameters that characterize cutting force signals (F_x, F_y, F_z), mechanical vibration (a_x, a_y, a_z), and acoustic emission (EA_{RMS}).

Keywords: Monitoring; turning CNC; surface finish; artificial neural networks; regression model

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1. Introduction

The ongoing need to improve productivity and raise the quality of products has spurred the design and development of automated on-line monitoring and diagnostic systems (Liang et al, 2004) that significantly reduce production times, quality control procedures, and the overall cost of the manufactured product. The most innovative advances have taken place in the field of on-line monitoring and diagnosis of machining processes (Teti et al, 2010), using sensors to register signals (Segreto et al, 2012) that provide useful and reliable data regarding the machine-tool-piece system. The real-time processing and characterization of these signals enables process and product quality parameters to be calculated i.e., premature wear of the tool cutting edge, anomalous mechanical vibration (*chatter*), deficient cutting conditions poor surface quality, geometric and dimensional defects, etc. (Shi et al, 2007). Current techniques for product quality control are based on post-process measurement applied to finished products, which entails two main drawbacks: extensive quality control inspection times, and the manufacture of defective products which raise production costs. On-line monitoring techniques provide real-time data on the cutting process which is used for diagnosing product quality indicators that detect anomalies in the machining process. On–line monitoring using sensors has proved to be efficacious for the diagnosis of automated (CNC) machining, and enables the instant application of corrective measures designed to avert the manufacture and cost of defective products. System optimization involves three basic elements: the correct choice of sensors for signal capturing on the monitoring system, accurate signal processing and characterization, and reliable predictive models with minor/low prediction errors. Current research (Teti et al, 2010) has focused on the capture of cutting force (F_c) signals, machine vibration (Upadhyay et al, 2013) (a_i), acoustic emission (*EA*), and a combination of this data output with cutting parameters (Hessainia et al, 2013) (*speed v, feed f, and cutting depth d*), and shaft and spindle power consumption. In many cases, no initial study is undertaken to adjust these signals to each specific circumstance or to precisely determine the predictive models to be applied, given that fewer signals entail lower computational cost and the use of fewer sensors.

Moreover, surface finish is one of the most frequently used indicators for the quality control of machining operations (García-Plaza et al, 2009), which is a crucial aspect directly linked to cutting process conditions: cutting parameters (v, f, d), tool geometry, type of workpiece material, tool material, use of cutting fluids, vibrations (*chatter*), machine-tool, etc. (Liang et al, 2004). Given that these factors are not systematic they are often difficult to assess and establishing initial estimates may be complex task. Predictive techniques based on mathematical or statistical models can provide reliable calculations of a range of cutting process and product quality control parameters. Regression models are among the techniques most extensively used by researchers (García-Plaza et al, 2009), since they are relatively simple with good predictive power. Alternatively, numerous studies have applied a predictive methodology based on artificial neuronal networks (Asiltürk et al, 2012), which is more complex to design and optimize given that all of the elements in the network are highly interconnected (Karayel et al, 2009).

In this study two prediction methods i.e., regression models and neuronal networks, were used to assess three types of on-line signals that are widely used for the on-line monitoring and diagnosis surface finish (*Ra*) in CNC taper turning operations. The signals were captured using three sensors: a triaxial dynamometer to register orthogonal cutting force (F_x, F_y, F_z) components, a triaxial accelerometer to capture machine vibration signals (a_x, a_y, a_z), and a RMS acoustic emission (EA_{RMS}) signal sensor commonly referred to as a piezotron. Signals were analysed individually and in combination according to the predictive model being applied, and its predictive reliability and efficacy.

2. Experiments

A total of 64 machined workpieces underwent exterior cylinder turning on a computer numerical control (*CNC*) lathe. The experimental design was based on a (4^3) factorial design of three factors at four levels: cutting speed *v (m/min)*, feed *f (mm/rev)*, and cutting depth *d (mm)*. Table 1 shows the combinations of parameters and levels for the 64 workpieces.

The experimental workpieces material was standard stainless steel *AISI 1045*, frequently used for the machining of components and products that require a degree of machining resistance. The machined workpieces shown in