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Automatic multiple sensor data acquisition system in a real-time production environment

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Abstract

This paper presents a multiple sensor automatic data acquisition system deployed on a CNC turning center in a real-time production environment at Schivo Precision, Waterford, Ireland. The machine has been fitted with a variety of sensors measuring acoustic emission, cutting force & vibration installed at the turret of the machine, coupled with an automatic image acquisition system monitoring the wear on the tools in real time after each operation. The combination of sensors and data acquisition is novel in that it brings together all the currently popular sensoring techniques in the field of tool condition monitoring and tests the validity of these techniques in a live production environment. The sensor data acquisition and optical tool wear measurements are controlled by a computer automatically with no intervention from the machine tool operator in normal production on a variety of component geometries, materials and cutting inserts. All the acquired data is available on-line for the research partners in the various countries. Independent operator feedback on the performance of the process in terms of both product dimensional stability and machined surface stability is used for evaluation of the acquired data applicability for tool condition monitoring.

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1. Introduction

In Precision Engineering, and in particular in the modern high accuracy CNC machining industry where product tolerances are required to be maintained within the single figure micron wavelength, there is much focus on the use of technology for the post manufacture inspection of the products, for example through the use of CMM machines. This expectation has been driven through the accuracy of modern CNC machines and their use in the production of products for the medical, diagnostic and nano-technology sectors.

However there is a significant commercial disadvantage when a product discrepancy is detected during a final inspection as opposed to failure detection during the manufacturing process on the machine. Significant resources have been allocated to the manufacture of the product, and detection of an issue at this point is costly due to machine time, material, and lead time to the customer.

There is currently no reliable method whereby the operation of a CNC operation can be scientifically measured within a true production environment that will give a reliable analysis of the production process.

There has been many years of research undertaken within the CIRP community to determine a methodology whereby the efficiency and effectiveness of the various material removal processes in modern manufacturing can be monitored and evaluated. Such has been the degree of activity in the area that down through the years a number of state of the art reviews have outlined the progress thus far.

The most recent was the keynote paper presented by Teti. *et al* [1] in 2010 which provided a broad ranging review of the most recent developments in the art and the technology under development and this paper provided an excellent snapshot of from where the research had come, and where the research was going.

When read in chronological order the previous reviews that had been undertaken, by Byrne *et al* [2] in

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1995, by Tonshoff *et al* [3] in 1988, by Tlusty & Andrews [4] in 1983, and by Micheletti *et al* [5] in 1976, demonstrated the pace at which the understanding of the various material removal processes have developed, and also serve to illustrate the rate at which the associated technological deployment has been enhanced.

The literature shows that a number of variables within the process have been evaluated and experimentation has served to both discount variables and prove the merit of the variable depending on the approach taken by the researchers.

The CNC machining process variables that have been examined include motor power and currents [6], machine vibrations, temperature [7,8], force and torque analysis [9,10], ultrasonic evaluation [11], workpiece irradiation [12], audible sound energy [13,14] and acoustic emissions [15,16]. In each instance it can be argued from the evidence in the literature that each of these examined variables has worthwhile information, but there is also evidence to discredit each of these elements on a standalone basis.

Increasingly the research community has evaluated approaches to this problem that uses the application of multiple sensors [17,18], and also has increasingly investigated smarter methods of signal conditioning and computational analysis of the sensor signals employed during experimentation.

To do this requires intensive knowledge of various process conditions, and the experimentation that will be further outlined in this paper aims to add to the research and the industrial communities understanding of these variables.

The research has shown that among the most promising variables within the CNC machining operation that provide information on the performance of the operation are force sensing, acoustic emissions, and vibration.

The combination of acoustic emissions and vibrations has been examined in detail, Al-Ghamd & Mba [19] demonstrated that the use of AE, combined with vibration analysis, was shown to be beneficial in the identification and estimation of defect size in bearings. Augereau *et al* [20] examined the use of acoustics to determine damage levels in 304L SS subjected to various treatments.

Otman & Jemielniak [22] examined catastrophic tool failure (CTF) and concluded that the AE bursts detected during the experimentation may not be reliable measures of catastrophic tool failures. Among other research into the use of AE to predict CTF, there is evidence to support the premise that ongoing continuous monitoring of the process will pre-empt catastrophic failure, such as outlined by Holroyd [23].

A number of detailed studies have been undertaken to determine the worth of the acoustic emission signal from a specific machining operation. The theoretical effectiveness of AE has been examined for fracture detection by Rao [24], in drilling by Gomez *et al* [25], in turning by Li [16] and Reddy [26] and in micro milling by Jemielniak & Arrazola [27].

A large body of research has been undertaken into associated signal pre- and post-conditioning methodologies by Jemielniak [28], Wilkinson & Reuben [29], who examined tool wear prediction using multiple sensors and artificial neural networks.

In recent years there have been a number of collaborative projects between industry and academia investigating the control of the material removal and forming processes. In 1996 a project was undertaken by Lazarus [21] which was sponsored by Allied Signal and undertaken in conjunction with the US department of energy where a correlation was determined between the state of tool wear and the level of acoustic emissions (AE) and audible sound energy from the process. Although the project methodology did not have the level of sophistication available to today's researchers, it concluded that the premise was fundamentally sound.

More recently there has been considerable activity through EU funded projects. ADACOM [30] investigated a modular platform to allow the metal cutting process to self-adapt to changes in performance. IFaCOM [31] has been working on intelligent fault correction and self-optimising systems and has been investigating the usefulness of sensoring in the monitoring of high precision processes.

The research that will be outlined in this paper is also being undertaken as part of a funded research project. REALISM [32] is a two year project that has been funded under the EU's FP7 "Research for the benefit of SME's" programme. The project comprises consortium partners from a number of EU countries, as is detailed in table 1 below.

Country	Type	REALISM participant name
Poland	RTD	Warsaw University of technology
Ireland	SME	Schivo Group
Ireland	RTD	Waterford Institute of Technology
Italy	RTD	The University of Naples Federico
Italy	SME	Tulino SRL
Norway	SME	IDT Technologies
Norway	RTD	University of Gjøvic

Table 1

The objective of the REALISM project is the development of a multi-sensor system whereby the CNC machining operation can be effectively monitored and the process performance fed back in simple terms to the process operator, in real time. The experimentation that is outlined in this paper is the initial trials of the REALISM project.