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An expert system for setting parameters in machining processes

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A B S T R A C T

In this paper, an hybrid system is proposed for setting machining parameters from experimental data. A symbolic regression alpha–beta is used to build mathematical models. Every model is validated using statistical analysis then evolutionary computation is used to minimize or maximize the generated model. Symbolic regression α–β is used to build mathematical models by estimation of distribution algorithms. A practical case considering measured data of two machining process on three materials are used to illustrate the utility of the expert system because generates a set of parameters that improve the machining process.

1. Introduction

Setting machining parameters is a complex task because a validated model of the process is required, then a kind of a search procedure is used on the model to establish a proper set of input parameters. There are several forms to generate models; however, mathematical models are not black boxes. Neural networks could be a very precise model; however, they are black boxes where a explicit formulation about the correlation between variables and the effects on output response is not evident.

Linear regression could provide a good decision criteria about the impact of the input machining parameters on output response; however, in some cases, could generate poor models for predictions. Setting parameters of a process is equivalent to optimize a function, we establish a criteria about the function to maximize its response or minimize a cost derived from the function, per example; then a optimization tools can be applied.

Symbolic regression with genetic programming (GP) are commonly used for this purpose; however, there are several drawbacks like complexity to manipulate tree data structures, tendency to generate very large tree structures and consequently high CPU time consuming; otherwise, GP could generate compact formulas eliminating some variables that could be considered as useless.

In this paper the expert system proposed works with turning and milling processes. With little adaptations can be used in another processes inclusive not machining ones. Some machining systems are a challenge because there are a variety of parameters and materials that define the performance of the process. Turning is one of the most used process in machining and setting parameters in this process is made by experience, following tables from builders, or by trial and error. More advanced approaches have been used like experimental design and robust experiments (Motorcu, 2010), response surface methodology (Bhushan, 2013; Chauhan & Dass, 2012; Villeta, de Agustina, & Manuel Saenz de Pipaon, 2012), analysis of variance or ANOVA (Aouici, Yallese, & Fnides, 2011), grey relational theory or grey analysis (Ranganathan & Senthilvelan, 2011) and Taguchi methods (Gaitonde, Karnik, & Davim, 2009; Hanafi, Khamlichi, & Mata Cabrera, 2012; Maniraj, Selladurai, & Sivashanmugam, 2012). Other approaches requires a model to be used with optimization tools; regression models (Liang, Ye, & Zhang, 2012), neural networks (Senthilkumaar, Selvarani, & Arunachalam, 2012) are commonly used.

Using these models and by genetic algorithms (Jangra, Jain, & Grover, 2010) and particle swarm optimization (Raja & Baskar, 2011) the machining parameters of turning processes can be set. Milling is another machining process more used too like turning. Design of experiments, Taguchi methods (Ji, Liu, & Zhang, 2012; Kadirgama, Noor, & Rahman,2012), analysis of variance (Gopalsamy, Mondal, & Ghosh, 2009; Mustafa, 2011; Yang, Chuang, & Lin, 2009) and response surface methodology (Mangaraj & Singh, 2011) are the most used approaches for setting machining parameters. Optimization approaches like particle swarm optimization (Raja & Baskar, 2012), Kriging interpolation search techniques (Lebaal, Schlegel, & Folea, 2012) have been used for setting the parameters of milling processes too. Our proposal is based on symbolic regression, However, this approach using genetic programming has been few used (Raja & Baskar, 2010).

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Considering setting of parameters as an optimization problem, different criteria has been considered. Usually surface roughness is the principal response to determine the efficiency of the machining process turning or milling, however consumption time, cutting temperature, tool wear are example of responses that could be considered to improve the machining process. In this paper, improve the surface roughness will be the criteria for setting the parameters.

This paper is divided in five sections; this section is the introduction, Section 2 is a description of an hybrid system used for setting parameters. Section 3 is a description of the application where a comparison with linear regression and genetic programming is made. Section 4 is the application of the proceed hybrid system for setting parameters on the machining process given in the last section. Finally, Section 5 includes conclusions and future work.

2. An hybrid system for modelling and optimization of machining processes

Setting of parameters is important in machining process because could generate an improvement on quality on machined pieces (this reflected mainly by surface roughness), material removal rate (MRR) reduction of time processing, tool wear ratio (TWR) and cutting temperature, and others which importance depends of the process (Fig. 1). Tables of machine fabricants or information given by the provider of the material to be machined gives some clues about the most suitable set of parameter that must be used; however, all the materials are not included. Another way to establish the parameters is by the experience of the user, analogies with related processes or by trial and error.

A new system is proposed using evolutionary computation and α–β operators where a model is build and validated using statistical analysis on residuals, then, the same evolutionary algorithm can be used to set the optimum set of parameters. An expert system can be build integrating these approaches as is shown in Fig. 2.

The expert system executes the following steps:

1. Establish a unique machining process and one material.
2. Establish input parameters and response under study; other inputs must be fixed.
3. Capture measured data from historical records or an experimental design.
4. Develop models by symbolic regression α–β.
5. Validate every model using residual analysis.
6. Select the model considering low complexity and statistical metrics.
7. Use the model as an objective function.
8. Use an evolutionary algorithm to determine optimum values. These solution will be the ideal set of machining parameters that would improve the process.

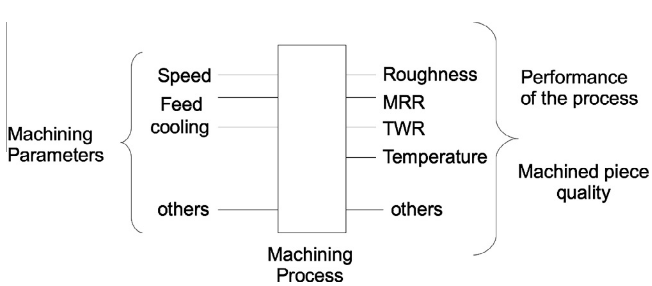

Fig. 1. Setting parameters properly could make improvements on the machining process.

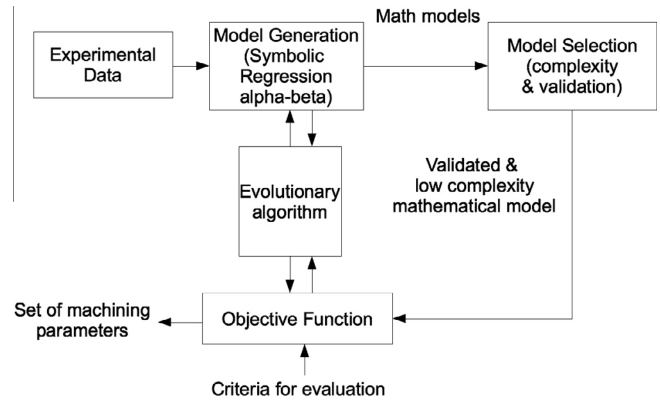

Fig. 2. Expert system for setting parameters on machining process.

An expert system is an assistant for the user of any machining processes. The requirement is the generation of an experimental data and a criteria about the desirable response of the process. Expert system returns a set of machining parameters that satisfy the desirable response. The measured data could comes from several sources, historical records, or a experimental design and contains a set of parameters used on the process and the response generated. Several experiments is required; however, when replication is not possible, a percentage of the measured data can be used for building the model and the rest is used for validation. The expert system uses an 80% of measured data for building a mathematical model, the rest is used for validation. Every block of the proposed expert system will be described in the following subsections.

2.1. Model generation by symbolic regression alpha–beta

In this approach, a mathematical equation is represented by the combination of α and β operators. An α operators is defined as a function that requires only one argument and applies only one mathematical operation. Considering a review of several mathematical models of real processes, 13 operations are chosen as α operators (see Table 1). An α operator uses two real number parameters called $k1$ and $k2$ and an integer that describes the mathematical operation. The α operator is defined as follows:

$$Opr_{\alpha}(x, k_1, k_2) = \alpha(k_1 * x + k_2) \quad (1)$$

where x is an input variable and α is an operation. Depending of the α operator selected, a specific mathematical operation that requires

Table 1
α Operator parameters and its related mathematical functions.

α Operator	Mathematical operation
1	$(k_1x + k_2)$
2	$(k_1x + k_2)^2$
3	$(k_1x + k_2)^3$
4	$(k_1x + k_2)^{-1}$
5	$(k_1x + k_2)^{-2}$
6	$(k_1x + k_2)^{-3}$
7	$(k_1x + k_2)^{1/2}$
8	$(k_1x + k_2)^{1/3}$
9	$\exp(k_1x + k_2)$
10	$\log(k_1x + k_2)$
11	$\sin(k_1x + k_2)$
12	$\cos(k_1x + k_2)$
13	$\tan(k_1x + k_2)$