Compensating high precision positioning machine tools by a self learning capable controller

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Abstract

The major part of positioning errors of multi-axis machine tools reveals systematic behaviour. Unfortunately, the dependency of these error on environmental and loading conditions passes through complex relationships for describing kinematic structure, machine elements mechanical behaviour, foundation characteristics, temperature distribution in operating conditions and workpiece mass properties.

This paper describes an approach to error compensation, developed within the ongoing European research project SOMMACT (Self Optimizing Measuring MAChine Tools). This project is intended to develop and to validate an innovative production hardware and control system founded on understanding, evaluating and controlling large machine tools production performances, based on a self learning controller capable to manage a large amount of measurements coming from environmental sensors, embedded metrological systems and other useful information, all related with the referring measurements conditions. The proposed architecture uses a support vector machine kernel and a fuzzy logic inference system as the fundamental mechanisms for detecting similarities among the collected data and the current condition, because these similarities concern not comparable fields whose contribution can not a priori be added directly.

1 Introduction

In the past, machine tools compensation has been addressed using different approaches, considering both the quasi-static and dynamic phenomena and introducing criteria of separation between systematic errors and random ones. In many cases, these techniques need to develop a mathematical model to describe the particular machine used, and are not easily reusable [1]. The latest developments in the field show a growing use of numerical algorithms based on statistical concepts to make self-adaptive compensation systems which can more easily be applied even in situations not identical [2]. Here is presented development that goes in the direction of the latest trends, exploiting a supervised inductive learning algorithms to obtain adaptive capabilities. It has been developed starting from a few basic considerations: first, the space of hypothesis cannot be a priori defined to obtain a general model of the error function curves; secondly, data input to the inference system show different characteristics: they may be part of earlier versions of the full table, partial or even unit elements obtained by reading on machine sensors or by comparing artifacts.

2 Similarities analysis

The first computation phase consists of choosing, within the database, the information that must be considered more relevant because collected in operating conditions more similar to current ones. Because the problem is not linear, but in general requires a robust solution that can avoid overfitting problems, it was implemented using a support vector machine kernel (SVM). In a nutshell, this means collecting in vectors the main characteristics of the load, the temperature field and other relevant parameters. These vectors, of size d_v, are projected in a vector space of dimension $d > d_v$. This remapping in a larger space allows to separate the vectors through a linear hyperplane properly calculated. The identification of separation hyperplanes is done considering, for each vector, that is for each set of conditions, the corresponding compensation value in the table.

Figure 1: A boring machine from Alesamonti

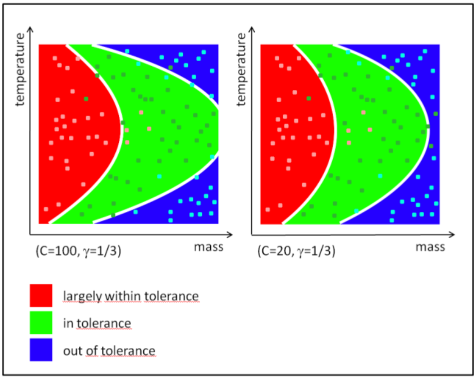

Figure 2: Example of SVM application to mass and temperature vectors

The figure shows some examples of basic situations obtained with an exponential separation kernel used to separate pairs of parameters labelled through the associate error. These are simplified representations of the real system in which the vectors are made up by a larger number of parameters. This solution results attractive because allows to manage as similar situations that lead to similar results through a compensation of opposite effects that arise from different environmental situations. Moreover, the proposed approach avoids the risk that only a small number of points appears close to the current conditions in all dimensions of the vector space. It also allows to overcome the limitation inherent alternative algorithms which treat properly only clusters with roughly spherical shape.

3 Best error table estimation and discontinuities regularization

If the separations obtained from the previous step were always clearly identified and they indicate compact and convex sets of conditions, it might be possible to directly obtain a good estimate of the current table values. Unfortunately, a certain level of noise in the data input and a not perfect correlation of these with output values should indeed be expected. To obtain an inference system capable of refining the estimate which has characteristics of strength, stability and generality, a fuzzy logic inference system has been implemented. For each point, it creates a set of membership functions, one for each environmental parameter, expressing the membership to quality classes, as shown in the example in figure 3.

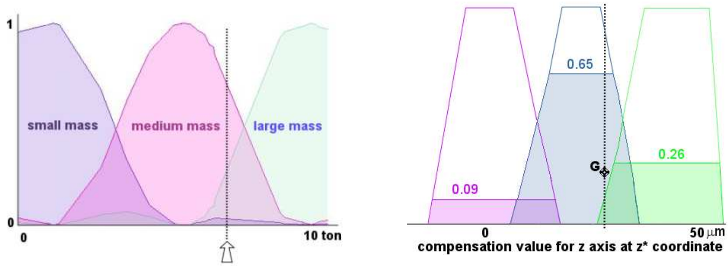

Figure 3: Example of membership function and the corresponding compensation on one axis in one table cell, on varying mass

The previous steps process independently each element of the compensation table, providing a general method to treat even incomplete error functions which could lack regularity and continuity. These are achived by a Gaussian blurring filter in 3 dimensions, whose values are used to build a convolution matrix which is applied to the compensation table obtained from the previous step.

4 Conclusions

An innovative approach to the problem of machine tools compensation has been shown. It uses artificial intelligence techniques to process data from a complex set of sensors that characterize machine state and operating conditions. Preliminary tests on some limited set of data provides promising results.

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