Predicting Machining Centre Geometric Tolerance Thresholds with Support Vector Machines

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Introduction

NC-Checker is a tool developed by metrology software products ltd. for data collection and benchmarking of geometric performance in CNC machining centres. It runs a series of probing cycles on a calibrated datum point within a machine volume, revealing the errors inherent in the system. It is then possible to compare these errors against both nominal positions and the typical operational conditions, using this data to assess the likelihood of quality part production but also to track any changes in geometric performance over time. Herein, *geometric performance* is defined as the tool tip or probe's deviation from nominal position as understood by the controller, affecting finished workpiece quality as a result of inaccurately machined dimensions. Due to a variety of error sources [1] inherent in machining operations, it is not possible to guarantee identical geometric performance at all times, and it is observed that geometric performance tends to drift over time. As such, machining centres undergo regular maintenance to ensure they are performing within the acceptable tolerances.

One key functionality of NC-Checker is the ability to set threshold limits on each tested parameter, providing the operator with a simple system to determine whether the machining centre is in a satisfactory state for operation or not. This is presented in the form of a *benchmark report*. Generally, the ability to edit these thresholds is restricted to the Manufacturing or Maintenance Engineer and is determined by the required precision of the part in current production. Through interference with the tolerance thresholds, there is the possibility of distorting the machining centre's actual health state as perceived in the NC-Checker benchmark report. This can have implications for finished part quality if the operator is using NC-Checker as a 'go/no-go' system, as is often the application of the software. Thus, in order to achieve effective monitoring of machining centre geometric performance, it is pertinent to explore the issue.

Method

Geometric health state data were acquired from an operational five-Axis CNC machining centre located in an industrial research environment, covering a six-month period at approximately weekly intervals. Four parameters were selected from the dataset for analysis in this study – the measured deviations in linear axes X, Y and Z; and measured deviations in rotary axis C (representing the rotation potential about the linear Z-axis).

The data were split into two sets, one comparing linear X with linear Y and the other linear Z with rotary C, conducted to allow visualisation and direct parametric comparison. The raw measured data were then compared with the engineer-determined threshold values for each respective benchmark test, and class labels were assigned based on whether this assessment had resulted in a 'pass' or a 'fail' for the machine tool's geometric performance. The data were split by a three-fold cross validation and the training set fed into a support vector machine (SVM) for predictive classification, including an optimisation step for model hyperparameters C (soft margin parameter) and γ (kernel length scale) [2].

Results

Fig. 1 and Fig. 2 present the models to predict the likely classification of a measured data point, based on past events as determined by engineering judgment. Modifications to the engineer-determined thresholds for acceptable performance are represented by the coloured rectangles; whilst the black decision boundary separates the two classification regions predicted by the SVM. Data points for the measured values are visually separated into + and o markers, for a benchmark pass and fail respectively. Note that some measured values for the deviation in C exceed the maximum engineer-determined threshold. Due to acceptable conditions in this region, the operator decided to proceed without updating the threshold but with this knowledge in mind. For the purpose of training the classifier, the decision was made to include all values up to and including 1.2 times the maximum engineer-determined threshold for the C-axis deviation, to account for this effect on the dataset. A value at the nominal location [0, 0] was also included in the training sets, based on the understanding that this value will always be deemed acceptable in a benchmark test.

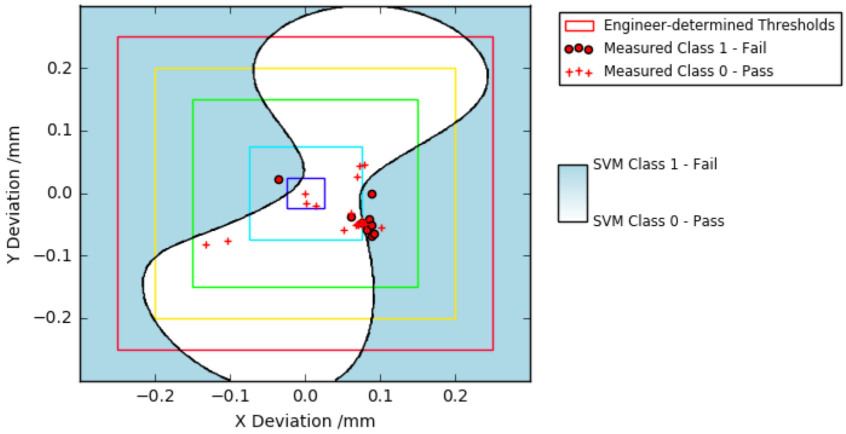

Fig. 1 – Predictive classification of parametric health states, comparing linear X and Y axes.

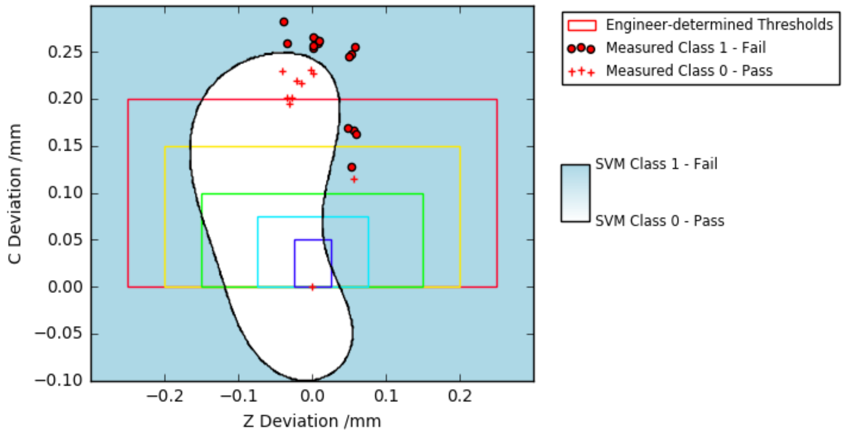

Fig. 2 - Predictive classification of parametric health states, comparing linear Z and rotary C axes.

Conclusions and further research

From the analysis, it is reasonable to deduce that modifications to the threshold values can skew perceptions of the machining centre health state. In Fig. 1, a cluster of measured data points classified by the engineer as 'failed' is observed, interspersed with three further 'pass'-classified data points. The actual operation as observed at these data points is near-identical with respect to the X and Y axes, so in the context of overall machining centre performance it would be more sensible to be grouped into a single class. Furthermore, it would be logical to assume that a tight cluster of data points represents a stable operating condition, as all parts produced in these states are subject to similar conditions. Clearly, deviation from nominal geometry is of the highest importance when assessing machining centre performance; however, it is also worth considering the stability of the system and the effects that this can have on finished part quality. Fig. 2 shows a consistent grouping of data points with just one outlier; however, in Fig. 1 the data points classified as 'pass' show considerable dispersion. Again, this weakens the argument for relying on engineer-determined thresholds for monitoring the overall system performance.

The SVM models will be used to predict the classification of future measured data points as determined by engineering judgement; data collection is ongoing and indefinite, so these results will be made available in the presentation. It is hypothesised that such an approach will have benefits in informing the threshold-setting requirement by identifying abnormal classifications, which could lead to a reduction in finished part quality and be difficult to interpret at a human level. Although the current approach and research focus is best suited to sense-checking the engineer-set thresholds, there could be future applications in automation and optimisation of the acceptable tolerance limits, minimising the requirement for calibration and subsequent machine downtime. However, this would require both sophisticated modelling and, crucially, detailed data input regarding the parts for production to implement.

Acknowledgements

A. Nixon, AMRC. Data collection and contextual information on the machining centre under investigation.

References

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