APPLICATION CAPABILITIES OF A GENERAL, ANN-BASED CUTTING MODEL IN DIFFERENT PHASES OF MANUFACTURING THROUGH AUTOMATIC DETERMINATION OF ITS INPUT-OUTPUT CONFIGURATION

Zsolt János VIHAROS

Department of Manufacture Engineering,
Technical University of Budapest
H–1521 Budapest, Hungary
Pf.91, Tel: (36-1) 463-2515, Fax: (36-1) 463-3178
Computer and Automation Research Institute,
Hungarian Academy of Sciences
Kende u. 13-17,H-1518, POB 63, Budapest, Hungary,
Fax: (36 1) 4667-503
Email:viharos@sztaki.hu, vihi@manuf.bme.hu

Abstract

Reliable process models are extremely important in different fields of computer integrated manufacturing. Outlying the fact that closely related assignments require different model settings, the paper addresses the problem of automatic input-output configuration and generation of ANN-based process models with special emphasis on modelling of production chains.

Production operations have several input and output parameters and the dependencies among them are usually non-linear, consequently, related operation models have to handle multidimensionality and non-linearity.

Artificial neural networks (ANNs) can be used as operation models because they can handle strong non-linearities, large number of parameters, missing information. A lot of efforts have been made to apply ANNs for modelling manufacturing operations [5][6][7]. The assignments to be performed determined the input-output configurations of the models, i.e. the parameters to be considered as inputs and the ones as output [1]. Considering the input and output variables of a given task together as a set of parameters, the ANN model estimates a part of this parameter set based on the remaining part. This selection strongly influences the accuracy of the developed model, especially if dependencies between parameters are non-invertable. In different stages of production (e.g. in planning, optimisation or control) tasks are different, consequently, the estimation capabilities of the related applied models are different even if the same set of parameters is used.

Based on their inherent learning capabilities, ANNs can adapt themselves to changes in the production environment and can also be used in cases where no exact knowledge is available about the dependencies among the various parameters of manufacturing [4]. In the case if there is no exact knowledge, it is unknown which input-output configuration of an ANN can satisfy the accuracy requirements of the model building, consequently, a method is needed for automatic input-output configuration of the applied ANN model.

One of the main goals of the research to be reported here was to find a general model for a set of assignments, which can satisfy accuracy requirements. Research was also focused on how to apply the general model for various tasks. The suggested optimisation procedure results in compromises among different viewpoints fulfilling daily requirements. Experiments show the applicability of this method.

1. Ann-based Approaches to Modelling of Machining Processes

The aim of this paragraph is to shortly overview the large variety of machining assignments and input-output configurations of the related ANNs. ANN applications in machining (e.g. in planning, in setting of tool and machine parameters, in monitoring and control) are presented in the paper of VIHAROS et al. [10]. It should be stressed that following the classic approach, in every application the input-output configuration of the applied ANN model is determined by the given assignment, namely known parameters serve as inputs and unknown parameters as outputs. The estimation capabilities of the applied ANN models are determined as results of the model building and testing stage.

A model building for creep feed grinding of aluminium with diamond wheels is presented by LIAO & CHEN [1]. The paper also pays attention to the problem that the measurement could not been satisfactorily handled by the chosen ANN model realising one-to-one mapping between input and output parameters.

2. Ann Applications for Modelling the Plate Turning

Surface roughness is one of the mostly used requirements of customers buying steel parts. The roughness requirement is expressed through prescribed value of the 'R_a' parameter of the surface of the part, consequently, among others the producer has to select the machining parameters appropriately. This paper addresses the problem of appropriate selection of feed, depth of cut and speed in plate turning using an ANN-based cutting model.

To build up an ANN model for plate turning, a hundred and fifty experiments were performed to produce data for learning and testing. All of the machining parameters were varied and the roughness of the produced surface was measured while performing these cutting experiments. Circumstances of cuttings were:

- Material: 42CrMo4.
- Machine: NC, Voest-Alpine, Nr. 085064, Type: WNC500S/1,
- Tool: CNMG12040843, cp 3, 1820091, p15, k20, radius: 0.8 mm,
- With cooling.

The speed was varied from 2.12 to 4.89 m/s, the depth of cut from 0.25 to 1.75 mm and the feed from 0.1 to 0.45 mm/revolution. Measured roughness values were between 0.4 and 4.95 micrometer. A hundred randomly chosen data were used to build up the ANN model and the remainder fifty data were used for testing. Several examples of ANN models in machining were presented in the second paragraph. In every application the input-output configuration of the applied ANN model is

determined by the given assignment, namely known parameters serve as inputs and unknown parameters serve as outputs. Using this classic concept for the problem of plate turning, the prescribed R_a parameter acts as input and machining parameters as outputs.

The experiments show that estimation accuracies are different for various machining parameters and conclude that estimations of depth of cut ('a') and speed ('v') are poor but estimations of feed ('f') are quite good. Based on the classic approach the averages of estimation errors can be reported as results without further investigations as in the papers presented above.

3. Selection of the Appropriate Input-output Configuration of the Ann-Based pLATE Turning Model

Outlying the multidimensional and non-linear nature of the machining operations and the fact that closely related assignments require different model settings, VIHAROS et al. [10] address the problem of automatic input-output configuration and generation of ANN-based process models with special emphasis on modelling of production chains. In this paper an algorithm is presented to build up a general ANN model through automatic selection of its input-output configuration. The algorithm does not have any regard to the given assignment of engineers, its target is to satisfy the accuracy requirements. The following three tasks are solved with help of the developed algorithm:

- Determination of the (maximum) number of output parameters (No) from the available N parameters which can be estimated using the remaining $Ni = N - No$ input parameters within the prescribed accuracy.

- Ordering of the available parameters into input and output parameter sets having Ni and No elements, respectively.

- Training the network whose input-output configuration has been determined in the preceding steps.

This algorithm was used to determine the appropriate input-output configuration of the ANN-based plate turning model. The allowed maximum estimation error was ±5%. This algorithm resulted in a general ANN-based turning model with parameters of 'f', 'a' and 'v' on the input and 'R_a' on the output side. The same results were obtained by repeating the algorithm with various numbers of hidden nodes, consequently, dependencies between these four parameters are non-invertable. This fact explains the existence of multiple solutions for the given assignment introduced above. *Fig. 1* illustrates an example of the local dependencies among these parameters learned by the general ANN model taking feed rate at a constant value.
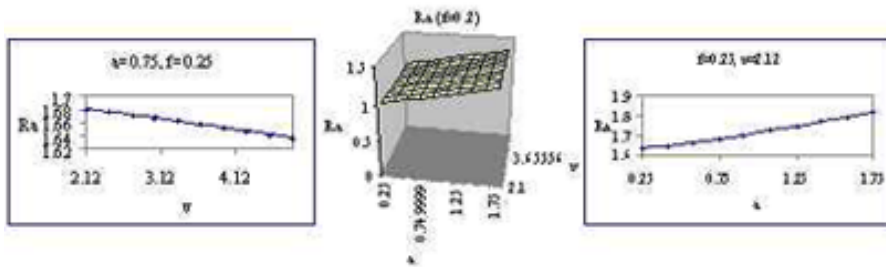
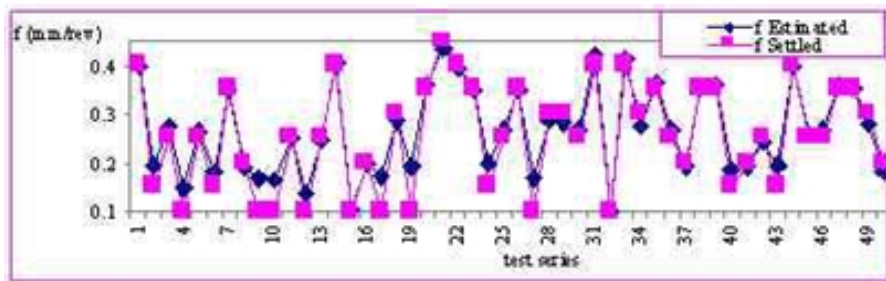Fig. 1. Learned dependencies among parameters

Fig. 2. Good estimation of the feed rate ('f') using the introduced new method

4. Estimations of Machining Parameters

MONOSTORI & VIHAROS presented a method for solving different assignments of various levels and stages of machining with the general ANN model resulted by the above referred method [9] [3]. This algorithm searches for the unknown parameters of the general ANN model without having any regard to the input-output positions of them. To solve the assignment presented above the unknown 'a', 'f' and 'v' parameters can be determined based on the known value of the 'R_a', however, the 'R_a' is on the output and the other ones form the input side of the ANN model. To show the capabilities of the ANN model, the estimation errors of the parameter 'f' were determined using the fifty test data. Fig. 2 shows estimated and real values of 'f' and concludes that the 'f' can be estimated quite accurate using the introduced methods. It indicates that there is no significant difference between the new and the classic approach regarding estimation of the parameter 'f', consequently, using any of the methods the feed rate can be determined quite accurately.

Results are different in cases of parameters of 'a' and 'v'. These parameters cannot be estimated with the required accuracy based on the classic approach. This fact can have two reasons:

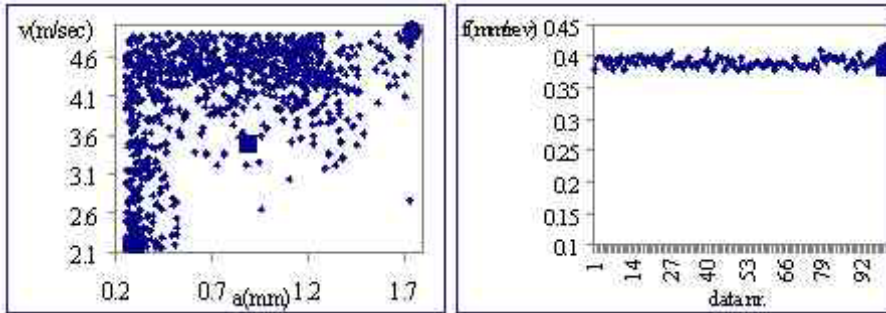• There are no dependencies between these parameters and roughness, or

Fig. 3. A thousand of possible machine settings are presented as small rhombuses in the pictures to produce the surface with the given roughness. Circles in the pictures represent the original machine setting. Large squares represent estimation of the classic method.

- in the classical approach the input-output configuration of the applied ANN model was not appropriate.

Fig. 1 shows that there are dependencies between these parameters and roughness, consequently, inadequate ANN models can be built up following the classic approach. Also the different input-output configurations resulted by the classic and by the new approach indicate this conclusion.

5. Multiple Solutions for the Given Assignment

Results show that dependencies between 'a', 'f', 'v' and 'R_a' are non-invertable, consequently, there are several solutions for the given assignment presented above. To present a field of possible solutions, the search for the unknown machining parameters was repeated a thousand times for one prescribed 'R_a' value. Solutions are presented in *Fig. 3*.

It concludes that the allowed interval of 'f' is quite small but there is a large number of solutions for choosing the appropriate 'a' and 'v' values to produce a surface with the prescribed roughness, consequently, optimisation of parameter setting can be performed as described in the next paragraph.

6. Optimisations of Machining Processes from Various Points of Views

Optimisations can be realised to satisfy some constrains or goals where there are several solutions of a given assignment. There are different approaches to optimise a given process or process chain [8]. A block-oriented software was developed
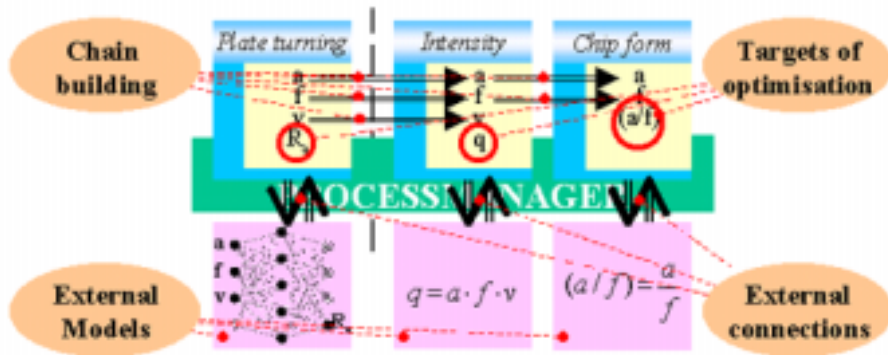
Fig. 4. The chain model for optimisation of the plate turning operation in three points of view

by MONOSTORI & VIHAROS [2] under the name "ProcessManager" to optimise operations and/or production chains from various points of view in the same time. Multiple objectives can be handled by the usual weighting technique.

This program was used to optimise the plate turning assignment. The optimisation indicates compromises among the customer, owner of the company and the employed engineer. At this problem optimisations were performed:

- From the point of view of the customer: His target is to buy a workpiece with the minimal surface roughness.
- From the point of view of the owner of the company: To reach the most profit, the productivity has to be maximised.
- From the point of view of the engineer: The most stability of the process has to be assured. This requirement is expressed through the a/f ratio.

Figs. 4 and *5* show the building up of the production line model and the possible compromises through values of the related parameters belonging together, respectively.

These results can be also used directly to support business decisions and compromises.

7. Conclusions

Motivated by the customer satisfaction, a general ANN-based operation model was built up for plate turning. Estimation capabilities of the classic technique and the new approach introduced by the author were compared showing the need of the automatic input-output configuration of the applied ANN models. The model building phase indicated that dependencies among parameters of the plate turning
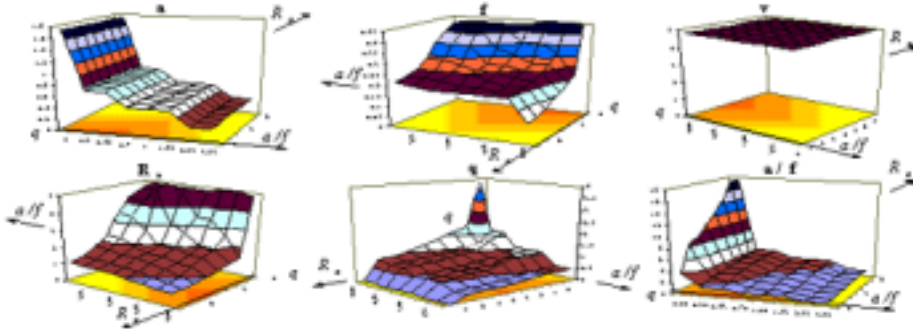
Fig. 5. Parameters resulted by the optimisation of the plate turning operation. These 'surfaces' are to be used only together, moving along the plane marked by 'R_a' and 'a/f' occurs with each of the diagrams at the same time. The corner marked by 'q' represents that the viewpoint of the company owner is the most important and moving along the axes 'R_a' and 'a/f' represents that these viewpoints (of customer and engineer) become to be more and more important against the viewpoint of 'q'. This moving expresses discussion to make compromises.

process are non-invertable, consequently, there is a free scope for optimisation. Compromises among viewpoints of customer, company owner and engineer are presented, showing that the realisation of the new concept works adequately.

Acknowledgement

References

[1] LIAO, T. W. – CHEN, L. J.: (1994), A Neural Network Approach for Grinding Processes: Modelling and Optimisation, *Int. J. Mach. Tools Manufact.*, **34** No. 7, pp. 919–937.
[2] MONOSTORI, L. – VIHAROS, ZS. J.: Multipurpose Modelling and Optimisation of Production Processes and Process Chains by Combining Machine Learning and Search Techniques, *The 32nd CIRP International Seminar on Manufacturing Systems, New Supporting Tools for Designing Products and Production Systems*, 1999, Leuven, Belgium, pp. 399–408.
[3] MONOSTORI L. – VIHAROS ZS. J.: Satisfying Various Requirements in Different Levels and Stages of Machining Using one General ANN-based Process Model; *15th International Conference on Computer-Aided Production Engineering; CAPE'99*, 1999, Durham, U.K., pp. 477–484.

[4] MONOSTORI, L. (1993): A Step towards Intelligent Manufacturing: Modelling and Monitoring of Manufacturing Processes through Artificial Neural Networks, *CIRP Annals*, **42**, No. 1, pp. 485–488.

[5] MONOSTORI, L. – MÁRKUS, A. – VAN BRUSSEL, H. – WESTKÄMPER, E. (1996): Machine Learning Approaches to Manufacturing, *CIRP Annals*, **45**, No. 2, pp. 675–712.

[6] MONOSTORI, L. – EGRESITS, CS. – HORNYÁK, J – VIHAROS, ZS. J.: Soft Computing and Hybrid AI Approaches to Intelligent Manufacturing. *Proc. of 11th International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems*, Castellon, 1998, pp. 763–774.

[7] RANGWALA, S.S. – DORNFELD, D. A. (1989), Learning and Optimisation of Machining Operations Using Computing Abilities of Neural Networks, *IEEE Trans. on SMC*, **19**, No. 2, March/April, pp. 299–314.

[8] TÓTH, T. – ERDÉLYI, F.: The Inner Structure of Computer Aided Process Planning Having Regard to Concurrent Engineering, *2nd International Workshop in Intelligent Manufacturing Systems*, Hungary, 1995, pp. 142–167.

[9] VIHAROS, ZS. J. – MONOSTORI, L.: Automatic Input-Output Configuration and Generation of ANN-based Process Models and Its Application in Machining, *Proceedings of the XII. International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems IEA/AIE-99*, Cairo, Egypt, 1999, pp. 659–668.

[10] VIHAROS, ZS. J. – MONOSTORI, L. – MARKOS, S.: Selection of Input and Output Variables of ANN-based Modelling of Cutting Processes, *Proceedings of the X. Workshop on Supervising and Diagnostics of Machining Systems of CIRP*, Poland, 1999 pp. 121–131.