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Application capabilities of a general, ANN based cutting model in different phases of manufacturing through automatic determination of its input-output configuration

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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 of the 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-linearites, large number of parameters, missing information. A lot of effort has 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 be used also in case where no exact knowledge is available about the dependencies among the various parameters of manufacturing [4]. In case if there is no such 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.

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 classical 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 calls the attention to the problem that the measurement could not been satisfactory handled by the chosen ANN model realising one to one mapping between input and output parameters.

ANN APPLICATIONS FOR MODELING 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 form 2.12 to 4.89 m/s, the depth of cut form 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 serves as inputs and unknown parameters serves as outputs. Using this classical 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 classical approach the averages of estimation errors can be reported as results without further investigations as in the papers presented above.

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] addresses 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:

1. 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.
2. Ordering of the available parameters into input and output parameter sets having Ni and No elements, respectively.

3. 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 were the results 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. Figure 1 illustrates an example of the local dependencies among these parameters learned by the general ANN model taking feed rate at a constant value.

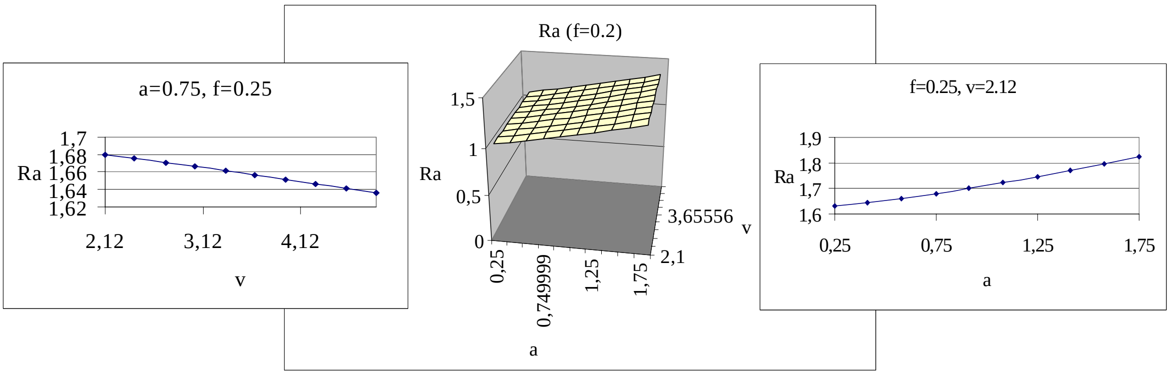

Figure 1. Learned dependencies among parameters.

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 of 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

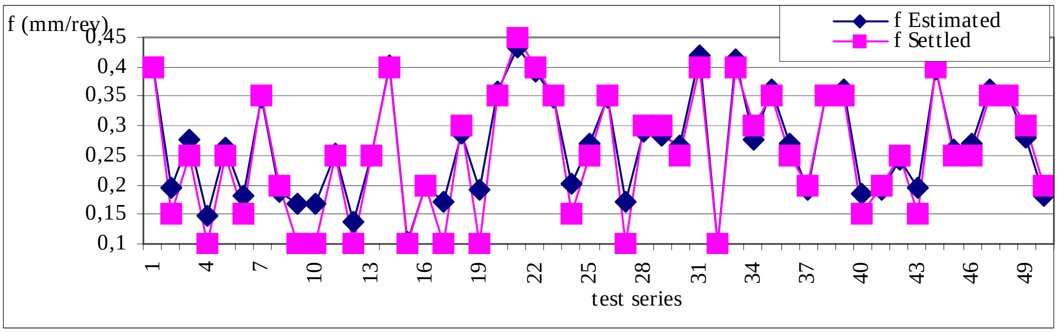

Figure 2. Good estimation of the feed rate (‘f’) using the introduced new method

of the ANN model the estimation errors of the parameter ‘f’ were determined using the fifty test data. Figure 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 classical approach regarding estimation of the parameter ‘f’, consequently, using any of the methods the feed rate can be determined quite accurate.

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

1. There are no dependencies between these parameters and the roughness, or
2. in the classical approach the input-output configuration of the applied ANN model was not appropriate.

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

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 were repeated a thousand times for one prescribed ‘R_a’ value. Solutions are presented in the figure 3.

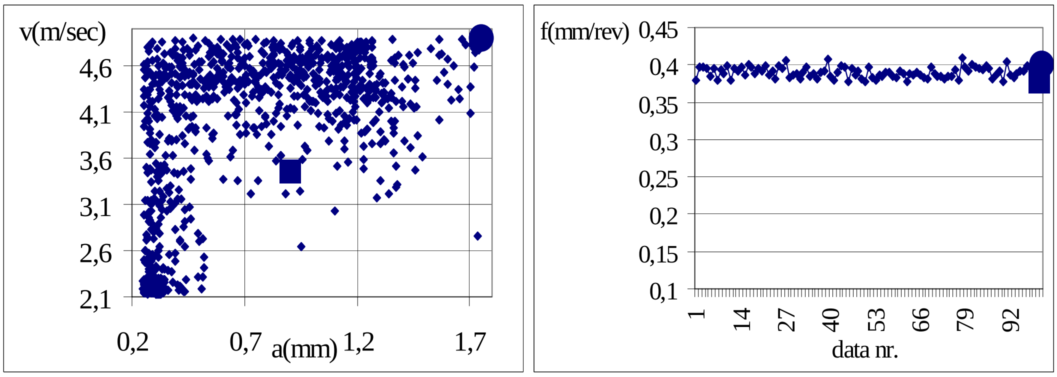

Figure 3. A thousand of possible machine settings are presented as small rhombuses in the pictures to produce the surface with the given roughness. Circles in the pictures represent the original machine setting. Large squares represent estimation of the classical method.

It concludes that the allowed interval of ‘f’ is quite small but there are 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.

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]. Block-oriented software was developed by Monostori&Viharos [2] under the name “ProcessManager” to optimise operations and/or production chains form various points of view in the same time. Multiple of 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:

1. From the point of view of the customer: His target is to buy a workpiece with the minimal surface roughness.
2. From the point of view of the owner of the company owner: To reach the most profit the productivity has to be maximised.
3. 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.

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

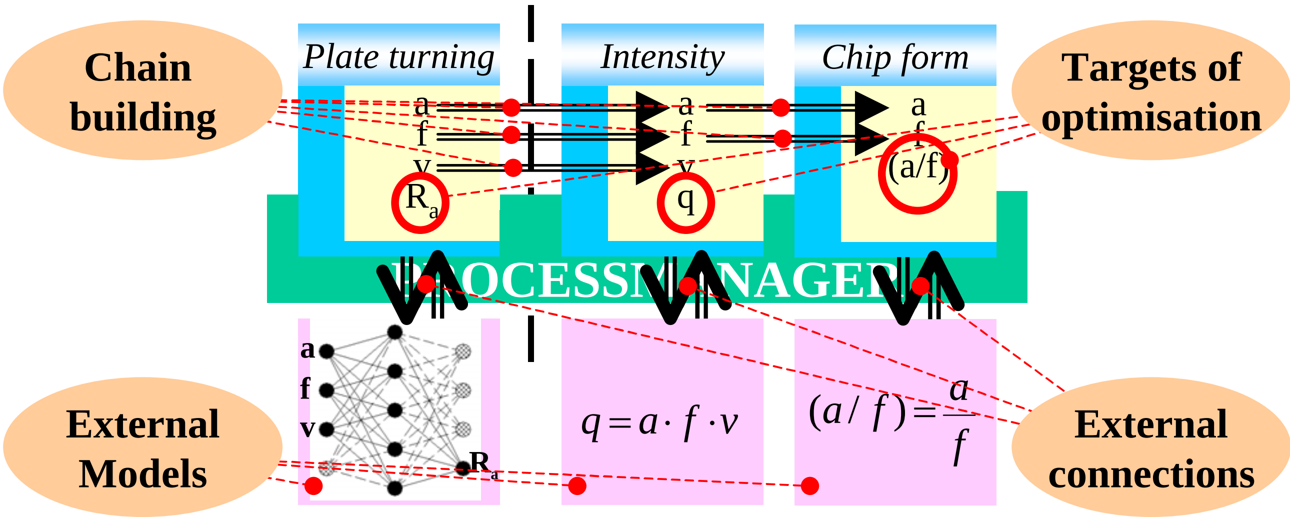

Figure 4. The chain model for optimization of the plate turning operation in three points of view.

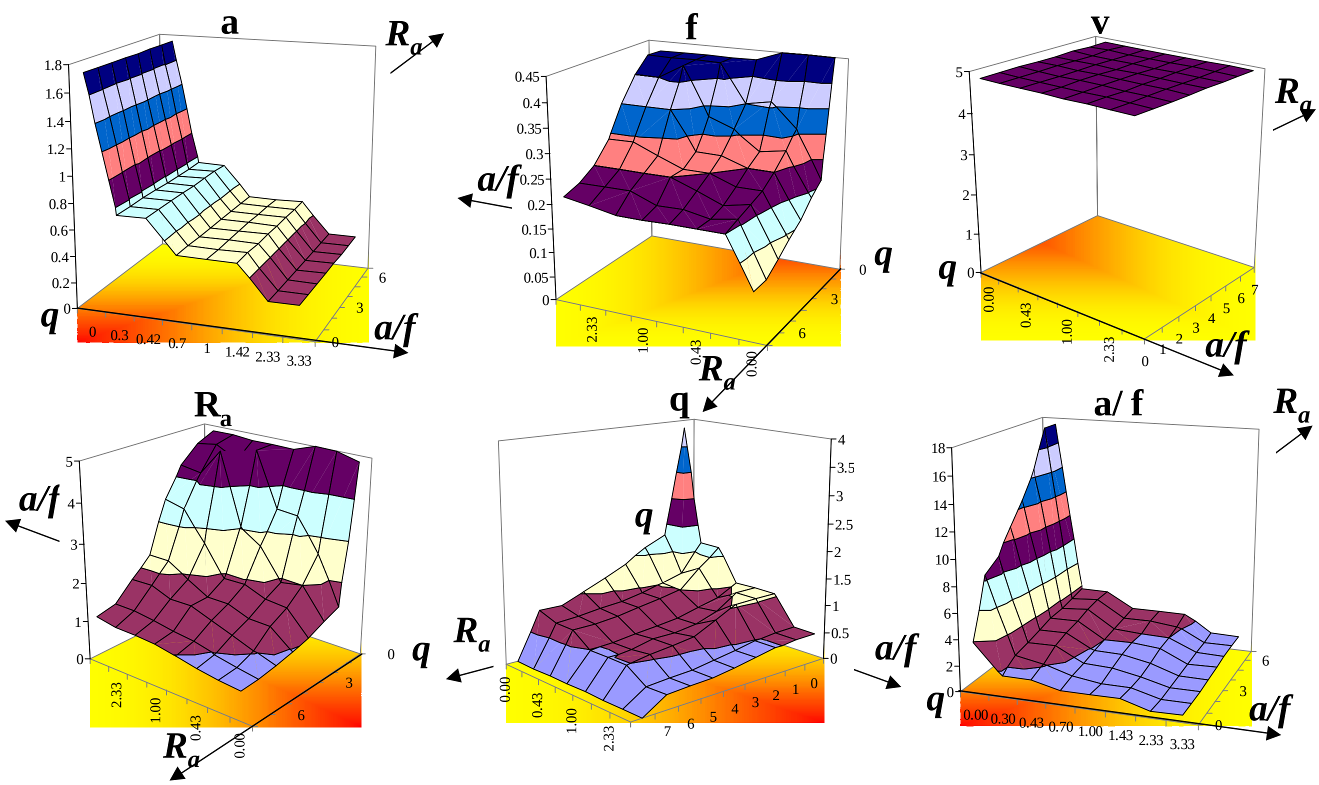

Figure 5. Parameters resulted by the optimization of the plate turning operation. These 'surfaces' are to be used only together, the moving along the plane marked by 'R_a' and 'a/f' occurs by each of the diagrams at the same time. The corner marked by the 'q' represents that the viewpoint of the company owner is the most important and the moving along the axes 'R_a' and 'a/f' represents that these viewpoints (of customer and engineer) becomes to be more and more important against the viewpoint of the 'q'. This moving expresses discussion to make compromises.

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

CONCLUSIONS

Motivated by the customer satisfaction a general ANN based operation model was built up for plate turning. Estimation capabilities of the classical 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 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

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