UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A NEURAL-FUZZY MODEL FOR MACHINABILITY DATA SELECTION IN TURNING PROCESS

KONG HONG SHIM

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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Especially Dedicated To

My beloved family, my teachers and my friends

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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October 2008

Chairman : Wong Shaw Voon, PhD

Faculty : Institute of Advanced Technology (ITMA) / Engineering

A neural-fuzzy model has been developed to represent machinability data selection in turning process. Turning process is a branch of machining process, which is used to produce cylindrical parts. Considerable efforts have been done to automate such machining process in order to increase the efficiency and precision of manufacturing. One of the issues is machinability data selection, which is always referred as the proper selection of cutting tools and machining parameters. This task is a complex process; and usually depends on the experience and skill of a machinist. Although sources like machining data handbooks and tool catalogues are available for reference, the process is still very much depending on a skilled machinist.

Previously, mathematical and empirical approaches have been attempted to reduce the dependency. However, the complexity of machining makes it difficult to formulate a proper model. Applications of fuzzy logic and neural network have been considered too to solve the machining problem; and have shown good potential. But, some issues remain unaddressed. In fuzzy logic, among the issues are tedious process of rules identification and inability to self-adapt to changing machining conditions. On the other hand, neural network has the issues of black box problem and difficulty

in optimal topology determination. In order to overcome these difficulties, a neural-fuzzy model is proposed to model machinist in selecting machinability data for turning process. The neural-fuzzy model combines the self-adapting and learning abilities of neural network with the human-like knowledge representation and explanation abilities of fuzzy logic into one integrated system. The characteristics of fuzzy logic would solve the shortcomings in neural network; and vice versa.

Generally, the developed neural-fuzzy model is designed to have five layers; input and output layers, and three hidden layers. Each of the layers has different classes of nodes; in which are input nodes, input term nodes, rule nodes, output term nodes and output nodes. The model is developed using Microsoft Visual C++ .NET (MSVC++ .NET). Object oriented approach is applied as the development process to enhance reusability.

The results from the model have been validated and compared against machining data of Machining Data Handbook from Metcut Research Associate. Good correlations have been shown, indicating the feasibility of representing machining data selection with neural-fuzzy model. The mean absolute percentage error for four different types of tools is below 3%, and averaging at 2.4%. Apart from that, the extracted fuzzy rules are compared with the general rules of thumbs in turning process as well as rules from other paradigm; and found to be consistent. This would simplify the task of obtaining fuzzy rules from machining data. Beside that, the model is compared with other artificial intelligence approaches, such as fuzzy logic, neural network and genetic algorithm. The neural-fuzzy model has shown good result among them. In addition, the characteristics of the model are studied and analyzed as well; in which include membership functions, shouldered membership functions and randomness.

This research has shown promising results in employing neural-fuzzy model to solve problems; in this case, machinability data selection in turning process. The developed neural-fuzzy model should be further considered in a wider range of real-world machining processes for learning and prescribing knowledge.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN MODEL NEURAL-FUZZY UNTUK PEMILIHAN DATA KEBOLEHMESINAN DALAM PROSES MELARIK

Oleh

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Sebuah model neural-fuzzy telah dibangunkan untuk mewakili pemilihan data kebolehmesinan dalam proses melarik. Proses melarik adalah satu daripada cabang proses pemesinan, yang digunakan untuk menghasilkan bahagian berbentuk silinder. Banyak usaha telah dijalankan untuk menjadikan proses pemesinan begini automatik, bagi meningkatkan kecekapan dan ketepatan pembuatan. Salah satu daripada isunya ialah pemilihan data kebolehmesinan, yang selalu dirujuk sebagai pemilihan wajar peralatan pemotongan dan parameter pemesinan. Tugas ini adalah satu proses yang kompleks, dan selalu bergantung kepada pengalaman dan kemahiran seseorang jurumesin. Walaupun terdapat sumber seperti buku panduan data pemesinan dan katalog peralatan untuk rujukan, proses ini masih lagi bergantung kepada seseorang jurumesin yang berkemahiran.

Sebelum ini, pendekatan matematik dan empirik pernah dicuba untuk mengurangkan kebergantungan ini. Namun demikian, kompleksiti pemesinan menjadikannya sukar untuk merumus satu model yang wajar. Aplikasi logik fuzzy dan rangkaian neural juga telah dipertimbangkan untuk menyelesaikan masalah pemesinan ini; dan telah menunjukkan potensi yang baik. Tetapi, terdapat isu-isu yang masih belum

diselesaikan. Dalam sistem logik fuzzy, di antara isu-isunya ialah proses pengenalpastian peraturan yang meletihkan dan ketidakdapatan menyesuaikan diri kepada keadaan pemesinan yang berlainan. Sebaliknya, rangkaian neural pula mempunyai isu-isu dalam masalah kotak hitam dan kesukaran dalam penentuan topologi yang optimum. Untuk mengatasi masalah ini, satu model neural-fuzzy dicadangkan untuk memodelkan jurumesin dalam pemilihan data kebolehmesinan dalam proses melarik. Model neural-fuzzy menggabungkan kebolehan penyesuaian diri dan pembelajaran rangkaian neural dengan kebolehan perwakilan pengetahuan manusia dan penerangan logik fuzzy dalam satu sistem berintegrasi. Ciri-ciri logik fuzzy akan menyelesaikan kelemahan dalam rangkaian neural, dan begitu juga sebaliknya.

Secara amnya, model neural-fuzzy yang dibangunkan ini direka mempunyai lima lapisan; iaitu lapisan input dan output, dan tiga lapisan tersembunyi. Setiap lapisan ini mempunyai kelas-kelas nod yang berlainan; yang mana adalah nod input, nod input sebutan, nod peraturan, nod output sebutan dan nod output. Model ini dibangunkan dengan menggunakan Microsoft Visual C++ .NET (MSVC++ .NET). Pendekatan berorientasikan objek digunakan sebagai proses pembangunan untuk mencapai kebolehgunaan semula.

Keputusan yang diperolehi daripada model ini telah disahkan dan dibandingkan dengan data pemesinan yang diperolehi daripada Buku Panduan Data Pemesinan oleh Metcut Research Associate. Korelasi yang baik telah dipaparkan dalam kajian ini; menunjukkan kebolehlaksanaan mewakili pemilihan data pemesinan dengan model neural-fuzzy. Min peratusan ralat mutlak untuk empat jenis peralatan adalah dibawah 3% dan puratanya adalah 2.4%. Selain itu, peraturan fuzzy yang diekstrak telah dibandingkan dengan petua am dalam proses melarik dan peraturan daripada paradigma lain, dan didapati konsisten. Ini akan memudahkan tugas mendapatkan peraturan fuzzy daripada data pemesinan. Model tersebut juga dibandingkan dengan pendekatan kecerdasan buatan lain, seperti logik fuzzy, rangkaian neural dan algoritma genetik. Model neural-fuzzy telah menunjukkan keputusan yang baik di antara pendekatan tersebut. Tambahan pula, ciri-ciri model neural-fuzzy juga dikaji dan dianalisa; yang mana melibatkan fungsi keahlian, bahu fungsi keahlian dan kerawakan.

Penyelidikan ini menunjukkan keputusan yang menggalakkan dalam menggunakan model neural-fuzzy untuk menyelesaikan masalah; dalam kes ini, pemilihan data kebolehmesinan dalam proses melarik. Model neural-fuzzy yang dibangunkan ini seharusnya dipertimbangkan lebih lanjut lagi dalam proses pemesinan dunia sebenar yang lebih luas untuk pembelajaran dan preskripsi pengetahuan.

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I certify that a Thesis Examination Committee has met on 23rd October 2008 to conduct the final examination of Kong Hong Shim on his thesis entitled "Development of a Neural-fuzzy Model for Machinability Data Selection in Turning Process" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

KONG HONG SHIM

Date: 3 December 2008

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List of Abbreviations

MDH	Machining Data Handbook
CNC	Computer Numerically Controlled
DNC	Direct Numerically Controlled
COG	Centre of gravity
GARIC	Generalized Approximate Reasoning-based Intelligent Control
FBFN	Fuzzified Basis Function Networks
RA	Regression analysis
RSM	Response surface methodology
FN-ASRC	Fuzzy-nets-based In-process Adaptive Surface Roughness Control
FAN	Fuzzy Adaptive Network
FNN	Fuzzy Neural Network
MIMO	Multi-input-multi-output
NFL	Neural-fuzzy library
MFC	Microsoft Foundation Classes
MSE	Mean squared error
MAPE	Mean absolute percentage error
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing

CHAPTER 1

INTRODUCTION

One of the most important processes in manufacturing industry is machining. Generally, machining is a group of processes that consist of removal of the material and modification of the surfaces of a workpiece after it has been produced by various manufacturing methods such as casting and forging. The other processes provide the general shape of the starting workpiece, while machining creates the final dimension, geometry and finish. As variety of work materials, variety of part geometric features, dimensional accuracy and good surface finishes are involved, machining is commercially and technologically important. With today's demanding productivity and profitability in manufacturing industry, machining has increasingly needed to be performed optimally.

As substantial amount of material is removed from the raw material in order to achieve required shape, machining is an expensive process. Furthermore, a lot of energy is expended in this process. Machining may be more economical provided that the number of parts required is relatively small; or the material and part shape allows them to be machined at high rates and quantities with high dimensional accuracy. It is important to view machining processes as a system, consisting of the workpiece, cutting tool, machine tool and production personnel. Machining cannot be carried out efficiently or economically without a through knowledge of the interactions among these four elements [1].

Turning process is one of the machining processes, which produces cylindrical parts using a single-edged cutting tool to remove material from a rotating workpiece. Three parameters can be used to describe turning process; in which are speed, depth of cut and feed. In the process, the cutting tool is set at a certain depth of cut (mm) and travels with a certain speed (m/ min) towards a direction parallel to the axis of the workpiece rotation. The feed is the distance the tool travels horizontally per unit revolution of the workpiece (mm/ rev). Turning process is widely used in core manufacturing processes and in a wide range of products. It has been investigated by various disciplines; which include not only mechanics and control theory, but economy too.

Machinability data selection is a complex process due to the number of possible variables and variations. Thus, this process cannot be easily formulated to meet design specification by any empirical or mathematical model. This includes the proper selection of machining cutting tools [2] and machining variables; in which among others are speed, depth of cut, feed, tool material and work material. Other variables such as the cutting fluid and temperature [3] are important as well. These machining data selection variables have major impacts on a machine performance in terms of productivity, reliability and product quality [4, 5]. In practice, optimized machinability data is obtained from a skilled machinist's experience and intuition [6, 7] in order to satisfy the required accuracy. Efforts have been made to capture this optimal machinability data into machining data handbooks and other media to serve as references when performing machining processes. However, there are still some problems with this practice. Therefore, models incorporating artificial intelligence technologies such as fuzzy logic and neural network are employed.

Fuzzy logic is a mathematical theory of imprecise reasoning that allows us to model the reasoning process of human in linguistic terms [8]. Fuzzy logic has been deployed to replace the role of mathematical model with another that is built from a number of rules with fuzzy variables such as output temperature and fuzzy terms such as relatively high and reasonably low [9-12]. While fuzzy logic allows the use of linguistic terms to represent data sets in the reasoning process, neural network is able to discover connections between data sets simply by having simple data represented to its input and output layers. Neural network are artificial and simplified models of the neurons that exist in the human brain [13]. It has the ability to learn the relationship among input and output data sets through a training process. The network can be regarded as processing device, and usually has some sort of 'training' rule whereby the weights of connections are adjusted on the basis of presented patterns.

Although applications of fuzzy logic and neural network in machining processes bring significant improvement to the processes, they are not without issues; in which are inherent to each of the paradigms. Most of the issues in fuzzy logic applications are in the formation of the fuzzy rules [14, 15], whereas the issues lie with the neural network application are mostly in its topology [16].

In order to overcome these shortcomings, this research proposes an integrated neural-fuzzy model for machinability data selection in turning process as they are complementing each other. The main feature of the neural-fuzzy model is that it takes advantage of the capacity that fuzzy logic stores human expertise knowledge