ON DIAGNOSIS OF MACHINING PROCESSES: A FUZZY APPROACH

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ABSTRACT

Manufacturing operations have empiric nature. Under any kind of problem during the execution of a given process, practical knowledge, experience and intuition have been used in solving these problems. However, many firms face problems since they do not have an adequate knowledge base to maintain and represent skills and expertise. Therefore, the importance of developing intelligent systems that assist the users in generating solutions for given problems. This paper presents a fuzzy based approach for a diagnosis system for solving machining problems. Because of the probability of having a great number of fuzzy rules, a rule navigation procedure, which aim is accelerating the searching process enhancing the system performance is proposed.

KEYWORDS: Diagnosis, Machining, Fuzzy Logic

INTRODUCTION

Manufacturing processes, specially, machining process, have essentially an empiric character. Thus, any initiative to solve practical problems or to carry out optimizations in the production will depend on experimental results, empiric appreciations and mainly, on technical experience. The great quantity of cutting parameters and variables involved in a manufacturing process (with a strong relationship among them) increases the difficult of optimization efforts. To ignore the fact that modification of given cutting parameter, serious prejudices can be caused to the manufacturing process. This fact leads to higher costs, low productivity indexes and low quality response. As an example for better understanding, consider the case of the intent to solve the problem of successive crashes of the cutting tool. To avoid tool breakages the technician or specialist could adopt tool geometry with a negative angle. However, if the cause of the problem were the resulting vibration caused by precarious rigidity of the machine-tool-fixture-piece system and, therefore, the solution adopted by the technician would increase the forces on tool surfaces causing a higher vibration in the operation, and the final collapse of the tool. An appropriate solution for this case would be, indeed, the simple selection of another tool material with a higher toughness. Many situations as the described here can be found within national and foreign industry.

In spite of the availability of information within catalogs and charts, plus the information that comes from the technical support that certain suppliers offer to manufacturers, the knowledge that professionals that act within the shop floor, is not properly systematized for the correct application and use in industry. This can lead to mistaken decisions and loss of time in the solution of problems. As a consequence, one will have an unnecessary elevation of the production costs, fall of the productivity index and a low quality performance, what can be reflected, in definitive, by the loss of competitiveness within a demanding market. All of this could be avoided or quickly overcome if the technical knowledge were available in a structured manner. In addition, if one considers the fact that systematized knowledge doesn't exist in a company, or there is a lack of feasible records and technical documentation, this can lead to erroneous decisions in process planning tasks. This might occur mainly when the professionals are inexperienced or when the resources and technological procedures evolve and people don't accompany this evolution.

During operation execution, some problems can arise. Many of those problems have to be recovered to avoid superior consequences. Among the problems that could exist during operations, we can highlight tool breakage, vibration, deficient quality, low surface integrity, chip control and many more. In the tentative of solving those problems, many sources can be used, such as machining handbooks, tool manufacturers catalogues, etc. However, almost all the
information contained in these sources has a quantitative character with nominal values. To use this information and advice for solving problems, a sensors system is needed. In other hand, many manufacturers do not have enough instrumentation to monitor or controlling operation’s behavior. Thus, any possibility of analyzing operation’s performance concentrates on visual and auditory observations made by humans, such as operators and/or technicians. Almost all the judgments made by technicians and operators when trying to solve any operations problems, is made through imprecise and qualitative information. Therefore, nominal and quantitative values and recommended actions in the literature can be considered as a good starting point only in trying to solve the operations problems.

Another factor that should be taken into account is the knowledge escape from the firm. It occurs when skilled professionals migrate to other companies. If the company wants to maintain its level of quality and competitiveness, it has to recompose the lost knowledge with new investments in training or incorporation of new professionals with similar skills and experience in the area. This can consume time, during which the company is exposed to new errors and risks, proper of any learning curve.

This article attempts to describe a fuzzy based approach as a basis for diagnosis in cutting operations. In the next sections, we will review the literature about topics such as cutting operations, expert systems and fuzzy logic. Finally, we describe the proposed approach. In the conclusions, we present the application potential and next actions pointing to implement a tele-diagnosis expert system for machining operations.

BACKGROUND

Among the manufacturing processes, machining has the major presence in industrial applications. It is known that approximately 80% of manufactured products have, directly or indirectly some machining operation. In addition, it is known that now the relation between effective time and downtime in machining corresponds to 70:30, the opposite of what happened before the 70s. That change occurred in function of new technological development and new machine tools. According to the paradigms of modern production, the economic and technical results of machining operations much depend on what happens during the effective cutting time (time where the tool is in effective contact with the piece) rather than the benefits obtained from improving unproductive phases.

This leads to a great responsibility in the process-planning phase. At this point, it is evident the necessity of applied knowledge to avoid problems and to generate optimized solutions aiming at technical and economically satisfactory processes. This is possible through at least three types of resources: hardware, tooling and knowledge. Great part of the companies have hardware and cutting tools with high performance to face the markets demands. The opening markets and globalization guarantees the access to the most modern resources of production to anyone that wants it. Therefore, that is not the problem, but the absence or lack of systematization of machining knowledge, as mentioned previously, has been the great barrier to continuous improvement in machining operations.

The solution would be the systematization of machining knowledge in the form of decisions rules, forming a knowledge base within the machining domain. This knowledge base would be available to end-users and would be expandable and updateable.

The availability of low costs of software dedicated to the knowledge systematization and specifically, Experts Systems platforms, allows users create their own knowledge bases. Therefore, within environments where knowledge is available, it is no more admissible to use the information in an unstructured manner, however is an imperative the creation of systems able to supporting and managing company knowledge.

EXPERTS SYSTEMS AND MANUFACTURING

Expert Systems (ES) in the area of Manufacturing have been investigated and applied recurrently the last years. A recent survey in the literature made by Pham and Pham (1999) shows how different tools of artificial intelligence (AI) are applied in manufacturing environments. Diverse experiences point to the implementation of control systems, pattern recognition, production, and process planning combining the use of neural networks, fuzzy logic and genetic algorithms. Monostori (2003) comments the obtained advances with applications of artificial intelligence in the production, and concludes that the most promissory application in this area are those related with Agents and Holonic Systems. AI applications that are related with implementations within the factory are vision, natural language recognition and the diagnosis. AI applications may go through several stages of the product life cycle,
from the Conceptual Design (Durán and Zanoni, 2001; Durán, 1999) until the programming in high-level languages of programmable devices (Durán and Batocechio, 1997a; 1997b; 1998), covering also the production programming, simulation, and training.

Considering machining operations, few have been published in applications of Experts Systems. This is, we believe, because a great quantity of variables associated in these processes. As Wong et al. (1999) pointed, the selection of cutting data is a complex task and it cannot be easily formulated through deterministic models. According to the mentioned authors, optimized information on appropriate cutting conditions is obtained basically, from the experience of operators and technicians, as well as, based on human intuition. Most of the taken decisions are made based on incomplete and approximate information, situation that leads to think of tools of AI to achieve correct computational modeling. Also according to Wong et al. (1999), Fuzzy Logic is an appropriate methodology for representing the strategy and actions that a specialist executes when select cutting tools and their cutting conditions. A similar work was presented by Almeshai and Oraby (2003) who proposed a solution based on AI to evaluate selected cutting parameters, comparing them with information of the available resources, production objectives and restrictions. The developed system by the authors seeks to predict the performance of operations through certain factors as tool wear, cutting forces, superficial quality, roughness and even vibration caused by the operation. The solution proposed by the authors consists on two fundamental steps, application of mathematical fundamental model, such as Taylor’s equations and other, and in a second stage, the use of logical algorithms for the implementation of the evaluation task of the conditions suggested by the user.

In spite of the few work found in the literature about AI techniques and processes planning in machining operations, we can conclude that for the type of information and the nature of the process, Fuzzy Logic is the most appropriate approach for automating the process planning process and representing machining decisions.

**FUZZY LOGIC AND MACHINING**

We can concentrate this discussion on three main and recent articles in the literature. Chen et al. (1995) presented a Fuzzy Logic based Expert System called SAM (Smart Assistant to Machinist) that basically aids the specialists in the selection of a tool and it establishes the using conditions, starting from imprecise and approximate knowledge. Fang (1995) proposed a system that allows diagnosing of turning operations, using fuzzy logic. The methodology used by the author introduces the concept of fuzzy relationship matrix to quantify the real threat that exists starting from a series of coming signals of behavior (cutting forces, vibrations and other parameters of the machining operation). The aforementioned article points to the use of the proposed system with an on-line machine tool monitoring module. More recently, Hasmi et al. (2000) presented a system of selection of cutting data for drilling operations based on a Fuzzy approach. The system allows selecting the cutting speed for this operation. According to the authors, the relationship among the hardness of a material and the cutting speed may be set as being of a Fuzzy type. Evaluating imprecise information starting from similar cases of drilling operations, materials hardness, different holes diameters and feed values, the system suggests the appropriate value of cutting parameters for the operation that is being planned.

**DIAGNOSIS EXPERT SYSTEMS AND INTERNET**

The Internet technology is presented as a powerful tool for quick dissemination of information and for taking decisions in distributed atmospheres. Maybe for that reason, this technology is beginning to be used for the diagnosis in different knowledge domains. For the same reason, the Internet technology has won significant space as a tool for the teaching-learning process, mainly when allied with multimedia resources. Ong et al. (2001) present a prototype that carries out the remote diagnosis of fault caused by tool wear in numeric controlled machine-tools. For such an objective, the authors have based the work on the technology of agents. They use specifically, two agents, an agent of learning and another agent whose function is to carry out the diagnostic of the operation. The breakthrough particularity of this proposal, it is that when the fault cannot be solved by the prototype, the same one has the capacity of acquiring knowledge, translating it into new rules using the called “rule builder.” Other examples that deserve to be mentioned are: Duan et al. (2003) who developed a system to diagnose problems in aquaculture using the web, specifically, looking for the causes of deaths in fish through the participation of an expert system that interacts with remote users through the internet. Another initiative that uses Internet to perform diagnosis functions is that related by Wang et al. (2003) that developed a system for
analysis of metallographies. The proposed system points to detect and to analyze particles of waste through samples. The system, called RIESFD is based on a hybrid solution combining Neuronal Networks and Fuzzy Logic to carry out the diagnostics. The main output of the system is the level of probability (fuzzy term) that each one of the faults (in a set of five possibilities) has, that is: high temperature, contamination for water, fatigue, and presence of wear particles or overloads.

In the articles mentioned previously and in others that we will mention to continue, is important to mention the didactic aspects in the use of these systems. For example, Parkinson and Hudson (2002) highlighted that multimedia techniques offer great potential benefits like teaching tools. Therefore, these techniques can be used to extend considerably the experience of learning. The authors show this potential through a study of applied cases to the teaching of the design in engineering. In this case, the authors emulate the knowledge of diverse experts in design and make the students interact with this knowledge as if they were part of a team of specialist participating in a collaborative project experience. A similar reference is Pooley and Wilcox (2000) who described a prototype of a multi-user system based on Internet for applications in a factory atmosphere. The system, entirely written in Java, allows experimenting with the relative knowledge about production lines and their fine programming and planning. Accordingly Cao and Bengu (2000), the technology of Agents is the one that has the biggest potential for effective environment of teaching through the Internet.

PROPOSED APPROACH

The approach is divided into two main parts. The first part points to structuring a knowledge base where intelligence on machining conditions is stored in a set of fuzzy rules. This fuzzy knowledge base is defined by machining specialists through the definition of a set of linguistic terms and its correspondent membership functions. Decisions rules are written using these terms and membership functions. The fuzzy rules will assist the user in resolving machining problems through the recommendation of cutting conditions and alterations in tool geometry or type.

Because machining operations involve a great number of variables and conditions, this approach could generate a great number of decisions rules. This constitutes a well-known limitation of rule-based expert systems affecting the implementation’s performance. Some authors have been investigating to develop efficient mechanisms for accelerating the search process within a rule based expert system. We suggest here the utilization of an interactive searching algorithm similar to the one proposed by Liu and Liu (2003). The authors created a meta-programming algorithm that builds a rule base in an automatic way. In other words, the propose is to implement a meta-mechanism that allows the system to select subsets of rules dedicated to certain symptoms and/or problems, concentrating the search process only on the rules associated with a particular element of the system Machine-Fixture-Part-Tool (MFPT). The selected elements are those related with the specific problem detected or declared by the user.

The proposed mechanism of navigation within the rule set can better understood through the following example (figure 1):

![Figure 1. Navigation algorithm for enhancing the search process](image)

As several problems or symptoms can arise simultaneously, it is necessary that the user identifies or qualifies the degree of intensity that each problem/symptom have. With such an objective, a scale of linguistic terms that represents the degree of intensity of each type of problem is manifested in a given application (Table 1) is defined.

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>Linguistic Terms</th>
</tr>
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<tbody>
<tr>
<td>Vibration</td>
<td>V.high, High, Medium, Low, Null</td>
</tr>
<tr>
<td>Power</td>
<td>High, High, Medium, Low, Very low</td>
</tr>
<tr>
<td>Consumption</td>
<td>Medium, Low, Very low</td>
</tr>
<tr>
<td>Tool Wear</td>
<td>High, Medium, Normal</td>
</tr>
<tr>
<td>...etc</td>
<td></td>
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</tbody>
</table>

Then, through a defined set of membership functions corresponding to the linguistic terms that represent the intensity which each one of the problems or symptoms are arising during a given application. For example, for the term of “high” roughness, it can be considered a membership
function delimited by the following limits (2.0, 10.0, 12.0, 20.0) as is shown in figure 2.

The problems can be associated, with different levels of intensity, to anyone of the elements of the system Machine-Fixture-Part-Tool (MFPT), this in the sense of expressing the impact that each one of those elements may have in the generation of the problem declared by the user.

![Figure 2. Membership function for the terms associated to the symptom roughness.](image)

That association can also be made using certain linguistic terms to represent the degree of influence among each one of the elements of the MFPT system and the probable problems. The terms are obtained from agreement or consensus of a set of judgments of one or more machining specialists. According to aforementioned example, the attributed linguistic terms could be as follows in Table 2.

Analyzing the vibration problem, table 2 shows that the elements that exert main influence in generating that problem are: the machine and the tool. From this the system will analyze just the subset of rules that are related to these elements and the mentioned problem. Through this strategy, the inference time will be reduced significantly and the system performance will be enhanced.

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>Machine</th>
<th>Fixture</th>
<th>Part</th>
<th>Tooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Roughness</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Power</td>
<td>Etc.</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Consumption</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<td>Chip Type</td>
<td>...</td>
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</tbody>
</table>

Table 2.

Suppose that, after the user inputs the information about a given cutting operation, plus the cutting data and the description of prevailing problem that is presenting. For instance, suppose that cutting tool vibration is the main symptom that manifests during the operation. Also, suppose that it is known that the element that influences operation stability, and therefore causes the existence of vibrations, is the cutting tool. The system will sweep the rules associated to that element (the tool), as observed in figure 1, and extract a series of recommendations to solve that problem.

Suppose that the relief angle in the described situation is 4°. The membership functions for the relief angle (α) are shown in figure 2. In this example, the discrete value of α (4°) crosses two membership functions associated to respective linguistic terms. Therefore, angle α can be partially considered as a small angle and partially as a medium angle. The term “partially” can be represented by a percentage or weight that will be used to evaluate the fuzzy rules and to extract the recommendations from the knowledge base. For example, and observing the figure 2, the relief angle of 4° can be considered in 75% as medium sized angle or 60% as a small sized angle. That is, the fuzzy rules that incorporate the term “small relief angle” will participate with an equivalent weight of 60% in the recommendations extracted from the knowledge base. Nevertheless, at the other hand, the rules that incorporate the term “medium relief angle” will have a weight of 75% in recommended actions. This supposes a combination of two or more recommended actions and these actions will be declared by the system with their respective weights. In a similar manner, when evaluating the rules that regard the cutting speed we use the membership functions shown in figure 4.

![Figure 3. Membership Function associated to the relief angle.](image)

![Figure 4. Membership functions of cutting speed.](image)

If the speed used in the situation described before were 220m/min. This value will be fuzzified to be used in the evaluation of the following rule:

\[ \text{If Vc is very high} \rightarrow \text{reduce Vc} \]

What will give a certain percentage of weight to the concept of very high Vc (20%). In function of such a value, the system will emit a given recommendation, in the case of to reduce the speed with a given weight.
CONCLUSIONS

A Fuzzy Based - Tele Diagnosis system was proposed. The system aims at resolving cutting operations problems from the description of a given cutting situation and its cutting conditions. The central hypothesis is that the knowledge about machining operations is unstructured, approximated and imprecise. This leads to the use of fuzzy logic techniques. When the user describes a given cutting situation, he/she does it using imprecise judgments and qualitative values. Through the use of fuzzy approach, the proposed methodology allows user to describe a given cutting condition, enumerating the resources that he is using and the problem that are arising during the operation with fuzzy terms. These terms are the same that those will be used to sweep the set of rules, searching for the recommendations for solving the described problem.

REFERENCES


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