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Machine tool error identification and compensation advice system

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Abstract

The costs of addressing machining accuracy problems can often appear to exceed the perceived benefits of reducing rework or scrap etc. These costs arise from assigning time and resources to analysing and fixing the problems. There may also be costs associated with consultancy if the required expertise is not available in-house. When accuracy problems are addressed, a lack of knowledge in certain areas may lead to unsatisfactory solutions.

This paper introduces a new expert system for addressing machine tool accuracy problems. The goal of this software is to be a Machine Tool Error Identification and Compensation Advice System (MTEICAS). Although in its early stages, the concepts and reasons behind the development of the software are described. An expert system development tool called Visual Prolog is being used to create the program, providing a number of advantages over traditional procedural languages such as C.

Designed for use in industry, the software employs a descriptive graphical user interface for retrieving information about the current machining application, and displaying information regarding possible strategies for improvement. Utilising a comprehensive and easy to use help system, the software will guide the user through many aspects of machine tool calibration and implementation of compensation strategies. To provide validation, a number of users with varying levels of experience will apply the system in real applications.

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1 Introduction

The majority of machined components today are made on CNC machine tools. Consequently there is currently a great deal of emphasis on improving the accuracy of these machines and a lot of research is being undertaken in this area.

Errors in machine tools are defined as differences between the actual position of the cutting tool relative to the workpiece, and the position indicated by the measurement system of the machine. There are a number of metrology devices used for the measurement of these errors (laser, ballbar, straightedge, electronic level etc.) and standards[1] exist providing guidelines for their measurement.

The main categories of error, namely geometric, load and thermal, have been addressed by research and many methods have been developed to reduce or compensate for them. This knowledge has been slow to enter industry; for example, volumetric accuracy has only recently been realised as a true measure of the production capability of a machine tool.

The demand for more accurate components is putting a strain on the machining capabilities that exist in many machine shops, increasing the number of problems such as out of tolerance parts, reworking etc. In addition, non-rigid and in particular thermal errors are becoming more significant, accounting for up to 70% of the total error content[2]. It is these errors that are particularly difficult to identify and less understood in industry.

1.1 Discussion of industrial accuracy problems

There is a lack of proven and definite solutions to industrial machine tool error problems. Deficiencies in techniques that have been developed often prevent their use on a variety of machines in a variety of applications. The standards that exist relating to machine tool accuracy are more involved with the calibration of machine tools, ensuring that data is taken correctly. Identifying that a particular error needs measuring is far more difficult and requires a much greater understanding of the machine tool and the manufacturing process. If errors exist, there are no guidelines available to help overcome the problems that may have been found.

It is often the case that an industrial problem will not get attended to because the relative cost of assigning time and resources to analysing and fixing the problem will exceed the perceived benefits of reduced reworking and scrap etc. It is also possible that the relevant expertise is not readily available and therefore consultancy may be required, again adding to the cost. When a company addresses a problem, a limited amount of expertise may result in inefficient compensation methods being applied or investigated. This can result in a solution that may not produce results to a standard that would justify the resources applied to the problem.

Many of the strategies developed by research for error compensation were designed to be a single basic approach, with the researchers proposing that it be used to solve all problems encountered. These methodologies can become

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complicated and time intensive to implement. Skilled people would probably be required to understand the technology. It is often the case that only certain areas need to be addressed on a particular machine, but understanding which ones can be difficult and require expert knowledge about machines and their errors.

1.2 Addressing the accuracy problems

In general, little work has been done to bring together proven technologies and methodologies for reducing particular sources of error that can be applied to most commonly used machine tools and working environments.

There is always a need for research into better and simpler error reduction techniques and these must be suitable for industrial applications. How and when existing calibration and error reduction strategies should be applied to an industrial accuracy problem also needs identifying. Complicated methodologies developed by research provide excellent results but are often unsuitable or unknown to the respective industries.

This paper introduces a new system designed to overcome many of the problems described above and help to increase the awareness and productivity of the machine tool and associated industries. A Machine Tool Error Identification and Compensation Advice System (MTEICAS) has been devised which incorporates a machine tool accuracy knowledge base and advanced graphical front end. Although as a program it is in its early stages, the development of expert logic is described and the software introduced. Also included is a description of how an accuracy problem might be tackled by the system. This will provide an insight into many aspects of the system and how they come together to form MTEICAS. An expert system development tool called 'Visual Prolog' has been used to create the program. This is a higher level language than most software such as Common Lisp whilst retaining flexibility and power[3].

Software relating to this project has been developed using forms of C, and therefore good interfacing capability, which Visual Prolog has, will become important at the later stages of development.

2 Expert system and knowledge base development

An expert system must have knowledge about the application it is designed to be an expert at, in this case identification and reduction of CNC machine tool errors. Secondly, logic is required to apply the knowledge in order to provide a solution to the problem at hand.

2.1 Researching the knowledge base

The system must be applicable to common machine tool types and configurations. This requires an understanding of a wide range of machines to help ensure the system is relevant for as much of the machine tool industry as possible. The many techniques available to calibrate machines and reduce errors

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must be understood in order to apply them effectively and realise their potential for particular applications.

Industrial collaboration has enabled comprehensive testing to be completed on a variety of machines. The process of completing geometric, non-rigid and thermal tests on these machines and the results obtained provides knowledge for the expert system.

2.1.1 Data analysis

To measure non-rigid errors, angular error change must be measured over a plane, which can be time consuming. Test results taken so far have suggested that there is a linear relationship between the change in error with respect to changing position and loading on the machine[4]. It is envisaged that a model can be created which uses information such as workpiece and fixture weight, position of the weight on the table and axis position to calculate error from simplified measurement tests.

Understanding the difference feedback transducers have on positioning accuracy is critical for determining possible causes of error. In particular is ballscrew expansion, which effects the position loop when rotary encoders are used. Tests have shown remarkably large errors of up to 300μm/m occurring after 1 hour of axis traversing. Detailed knowledge of errors such as these and methods of test on a variety of machines is key to the development of this system.

2.1.2 Estimating possible errors

The test results provide an insight into how and when errors may occur and their magnitude for different physical and environmental circumstances. This information has shown that thermal distortion follows, in most key structural elements, an exponential growth or decay curve, depending on whether heating or cooling is occurring. This distortion has been modelled by fitting a curve to the test data using a local minimiser routine. The returned parameters of the curve can then be used to calculate an error at any given time. Estimations can also be made without test data. The parameters of the exponential function are calculated using the experience of collected data, structural dimensions, in particular, distances from thermal datums and work rates etc. Timescales involved with manufacture of the component critical dimensions can then be used in the model to determine rough estimates of thermal distortion.

2.1.3 Cost considerations

Cost is the most important issue in industrial applications, and one of the main reasons for addressing the accuracy of a machine tool is to reduce scrap, reworking etc. The knowledge base must therefore consider factors that influence cost such as machine downtime, equipment, software, design and training costs etc. Many costs will be variable and dependant on the current application. Technical capabilities of the company will influence the resources required to implement technically variable solutions. In general, the expert

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system must attempt at to use the most time and cost efficient solution for any given application and accuracy problem that will provide the required data or error reduction.

2.2 Expert system development

Industrial accuracy problems are extremely varied and we need to know what they are likely to be. Four main reasons have been identified that require an investigation into the accuracy and possible improvement of a machine tool:

1. *Errors have been measured*: Previously retrieved calibration data in which an error seems to exist may need analysing. An example would be ballscrew expansion data collected using a laser interferometer. Prior to finding a suitable strategy for reducing the error, the machine and application should be considered to determine if the measured error would affect the accuracy of the part being manufactured, if it does then continue.
2. *Inaccurate components are being produced*: The majority of accuracy problems are related to component errors. This requires finding the causes of the component errors, then developing an efficient method of reducing the error according to the tolerance information for the component and test results. The next section describes in detail this option within the expert system.
3. *Feasibility study*: When a new component or batch is planned for a machine, there is often no guarantee that the machine has the required production capability. Costs can be incurred through lost time and scrapped materials if it does not. Using information about the new component, associated manufacturing process and the machine, possible areas for concern can be found. Carrying out suitable tests to gain data, techniques for solving any problems can be found.
4. *General accuracy improvement*: Understanding the capability of an existing machine is often required, especially when considering it for manufacture against a different perhaps new machine. It would also be beneficial to know the potential capability of the machine with error reduction techniques applied. No component or manufacturing process information is required, only details about the machine, much of which will be gained through calibration tests. The potential capability of the machine will be estimated based on the error reduction techniques suggested.

If we consider the process of addressing a component accuracy problem, three main areas of work are required.

- Identification of possible causes of the errors
- Testing methodology to confirm or deny existence of errors
- Development of an error reduction strategy

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Therefore, experts are required to effectively consider these areas. Figure 1 shows an overview of the system for identifying and reducing errors found during manufacture of a component/batch of components.

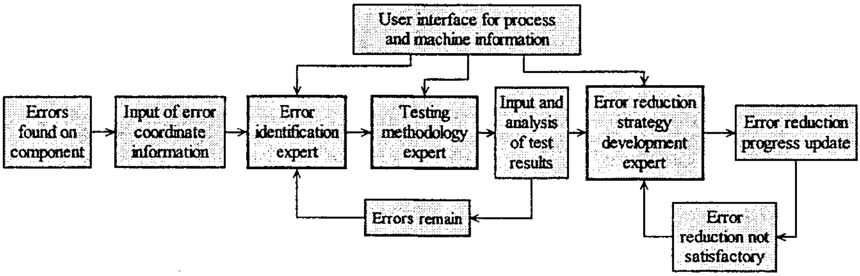

Figure 1: Overview of manufacturing error expert system

2.2.1 Identifying possible error causes

The 'error identification expert' uses co-ordinate and tolerance information to determine the direction and magnitude of the errors. Many causes of error are dependent on the movement of other axes such as squareness and angular errors; the coordinate details provide this information.

The knowledge base contains a list of all possible error causes that are selected and used to find a match using the sequence shown in figure 2.

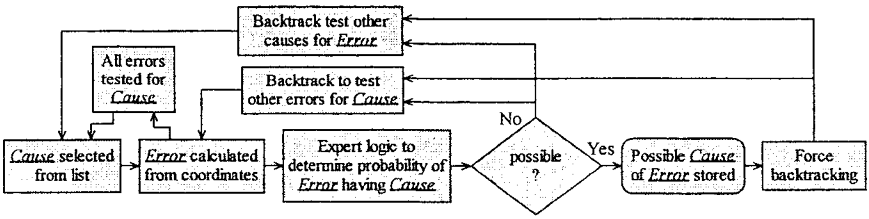

Figure 2: Error identification expert

For the expert system to be effective without being cumbersome, assumptions have to be made based on information received by the user. A trained machine operator will constantly make assumptions as he tries to make quick assessments of problems and their causes. The aim is to bypass time consuming tests to arrive at the source of the problem quickly.

By categorising machine tools in terms of their physical attributes, such as configuration, axis traverse lengths, table carrying capacity, feedback devices etc., quick determinations can be made based on some basic information. For example, certain configurations of machine are not susceptible to non-rigid errors and therefore would not have to be considered as a potential source of error.

2.2.2 Development of a testing methodology

The error identification expert provides possible causes of error. Before considering error reduction, tests must be carried out to measure the errors

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specifically. This data can be used to confirm or reject the existence of errors and estimate performance once error reduction strategies have been found. Timescales, skill levels, and equipment availability are particularly important when considering tests to measure errors. In order to minimise these requirements and related costs, this expert considers all identified possible error causes in parallel and with foresight. The system must be able to identify that a test required on one axis to investigate an error, provides a base set-up for possible tests on other axes or errors. In addition, the logic must take the opportunity to disregard unlikely causes of errors if a test set-up exists for another measurement that may provide significantly reduced testing times.

2.2.3 Error reduction strategy development

On completion of all the suggested tests, the system requests the appropriate results from the tests. These results are analysed against the tolerance information to determine their significance. If measured errors are found insignificant then the expert system must look for alternative causes until all the component errors have been considered. With factors relating to the machine, controller and user capabilities, the system will formulate error reduction strategies.

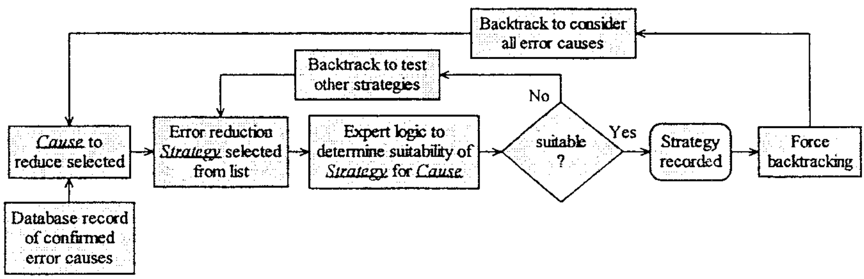

Figure 3: Error reduction expert

The decision to proceed with a particular solution will ultimately reside with the user. The system will however provide estimations of accuracy improvement, implementation time, and cost implications for the various error reduction/compensation techniques where possible.

Limitations, as with most expert systems, exist in that not all accuracy problems can be solved. Future technologies will not be considered either.

3 Overview of MTEICAS

The main attributes of the program being developed are briefly introduced in the following sections.

3.1 Using MTEICAS

The basic procedure for using the program revolves around completing 'Searches'. Four types of search exist for each of the reasons for using the program described in section 2.2. These are:

1. Calibrated error reduction
2. Manufacturing error reduction
3. General accuracy improvement
4. Component feasibility

3.2 User interface

The software is windows based and employs an advanced graphical user interface. This allows easy communication with the user while retrieving large volumes of information. Dialog boxes, such as the one shown in figure 4, provide the main means of communication.

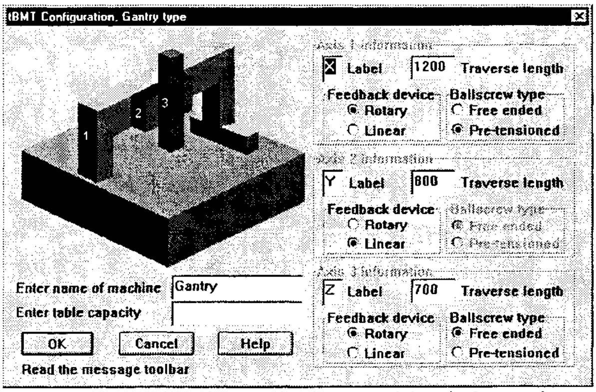

Figure 4: Dialog for retrieving machine information

3.3 MTEICAS help

Machine tool methods of test and error reduction techniques are suggested by the expert system but not explained. Therefore, MTEICAS incorporates a comprehensive help system for this purpose. The windows style help system contains detailed information about all aspects of using the program, machine tool error identification and error reduction techniques.

Similar to any other windows based program, the help is easily accessible. Every dialog that communicates with the user has a help button that provides information on how to input the relevant data. In addition, help is also provided about why the data is being requested and how it will effect decision making within the program. This will provide the user with a detailed insight into what the system is doing. The natural progression from this is that the user will gain knowledge and insight into machine tool accuracy issues.

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The help can also provide a machine and application specific guide to carrying out tests, and include tests not considered by the standards.

3.4 Program facilities

The main toolbar shown in figure 5 contains speed buttons for file management and initiating the searches.

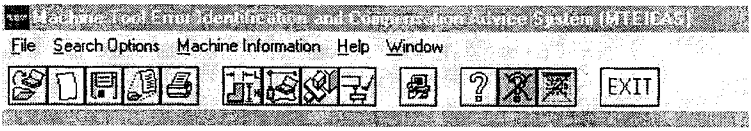

Figure 5: Program toolbar

Information entered during a search is categorised into either 'search information' or 'machine information', which can be saved for future use. When a dialog appears it first checks to see if any information already exists (either previously entered or loaded from a file). If it does then it displays the information for the user to edit if required. All the information can be printed and viewed at any time.

Settings can be changed to alter the way in which the search runs. One such option continues the search until tolerance is achieved without displaying progress to the user until the end.

The availability of equipment and the existence of error reduction systems already present on the machine tool are also part of settings.

4 Error reduction example

A company manufactures microwave filters used in communications systems on a small to medium sized vertical machining centre. The components are checked by passing microwave signals through the filter and measuring the reflected energy and filtered output. Dimensional inaccuracy causes deviations from the required parameters. Using grub screws in the casing, these parameters are tuned to give the required output. The goal of the manufacturer is to reduce the tuning time, which is typically 45 minutes. Figure 6 shows a flow diagram of a path through the expert system to reduce the errors on the above component.

The system outcome is to remove the tool change from the manufacture of the critical dimension in "fin gap" on the Z axis. No cause of error "fin spacing" on X axis was found. This is a valid outcome as no specific error was measured due to the performance testing used on the part. Consultancy with the company resulted in the same strategy for error reduction in that the Z axis, with no recommendations for other axes as any other errors were deemed insignificant.

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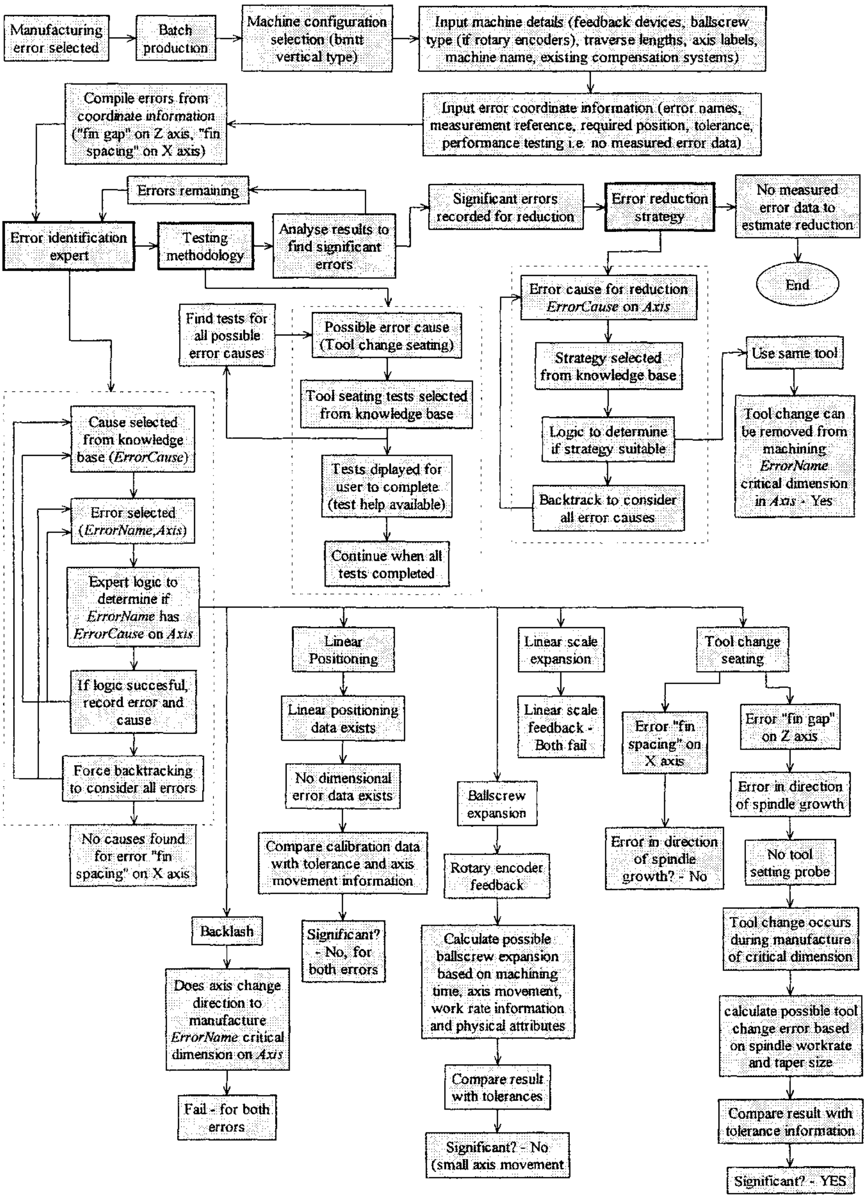

Figure 6. Microwave filter error reduction example

5 Conclusions

Although machine tool accuracy issues are complicated, it should be possible to produce a system that will help to identify and reduce industrial manufacturing problems for most commonly used machine tool types and configurations.

An advanced graphical user interface and comprehensive help system make the software user friendly and informative to aid the learning process.
A computer-aided system to aid the identification and compensation of CNC machine tool errors would provide a number of benefits to the machine tool and associated industries including:

1. Highlight possible simple solutions to existing problems.
2. Aid proper analysis of machine tool accuracy.
3. Improve Procedures for calibration and other measurement processes.
4. Encourage accuracy improvement projects on existing machine tools.
5. Aid the decision process involved with machine purchasing.
6. Increase awareness of machine accuracy in the machine tool and associated industries.
7. Reduce costs associated with accuracy improvement.
8. Reduce costs associated with scrap and rework.

The expert system being developed as MTEICAS will not be able to solve all machine tool accuracy problems but will help to identify and solve those most commonly found.

References

1. *ISO 230, Test Code for Machine Tools*, International Organisation of Standards, Geneva, 1988.
2. Bryan, J. International status of thermal error research, *ANNALS of the CIRP*, Vol. 39, Part 2, pp. 645 – 656, 1990.
3. Valavanis, K.P., Kokkinaki, A.I., Tzafestas, S.G., Knowledge-based (expert) systems in engineering applications: a survey, *Journal of Intelligent & Robotic Systems*, V10, P113-145, 1994.
4. Blake, M.D., Investigation into load effects on machine tool accuracy, *MPhil thesis*, 1995.