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Agent-Based Decision Support System for realizing Intelligent Machine Tools

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Abstract: - In order to implement artificial intelligence, various technologies have been widely used. Artificial Intelligence is applied for many industrial products and machine tools are the center of manufacturing devices in intelligent manufacturing devices. The purpose of this paper is to present the design of Decision Support Agent that is applicable to machine tools. This system is that decision whether to act in accordance with machine status is support system. It communicates with other active agents such as sensory and dialogue agent. The proposed design of decision support agent facilitates the effective operation and control of machine tools and provides a systematic way to integrate the expert's knowledge that will implement Intelligent Machine Tools.

Key-Words: - **Agent-Based System, Decision Support System, Intelligent Machine Tools, Multi-Agent System**

1 Introduction

The machine tools that emerged in 1800's have a wide range of famous and consuming demand production system. These industrial surroundings kept up until the middle of 1900's. The NC (Numerical Control) machine tools that developed at 1950's get ready for mass production with providing demand. After 1980's, machine tools that can do various works were developed which satisfies a wide range of consumer's demand. And machine tools that adapted to Artificial Intelligence emerged because of the development of computer and its application skills.

The development of machine tools to the direction of giving intelligence to them can be separated to two branches, the development of intelligent machine tools and development of manufacturing system, which include operating machine tools. Both should be followed by the development of intelligent machine

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tools [6]. The prerequisite for development of intelligent machine tools provided flexibility and adaptability to machine system according to the development of computers and network technologies, and then distribution control system became possible.

This paper includes the introduction of the case that the agent-based decision support system, which provides the best optimal operation condition to operators by knowledge to the machine tools, are developed and adapted for intelligent machine tools.

2 Intelligent machine tools based on multi agent-system

The word, intelligent machine tools, refers to a machine that gains new knowledge autonomously and that can communicate with other machines that have knowledge to acquire machine's knowledge. And according to this process, it inferences to decide current status of machine tools and it would well-adapt cope with various working condition.

At 1970, machine tools included NC equipped with computer was appeared and then the era of CNC (Computerized Numerical Control) were arrived. As shown Fig. 1, the PC-NC controller that has NC based on PC was appeared in the early 1990's. At this point, the major characteristics are that the NC technologies moved from hardware technologies to software technologies based on knowledge and intelligence [6].

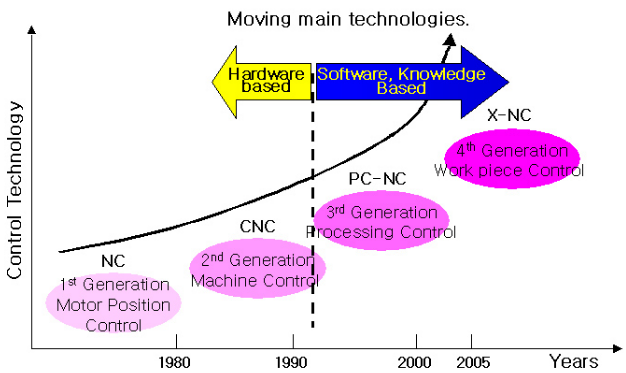


Fig. 1 History of NC development

The developments of intelligent technologies are ongoing in many fields; high-speed processing technologies such as recommendation of processing condition based on knowledge and decision of optimal tool routing, operating technologies such as analysis of failure, diagnosis and recovery, and structure optimization such as aging, monitoring of failures and prognosis of machine tool's factors.

On the other hand, implementing agent-based software onto PC-NC controller materializes the intelligence. The agent is a system that recognizes surroundings by the sensory organ and reacts to the surroundings by the effectors. The characteristics of software agent are autonomy, intelligence, perception, delegation and communication with other agents. The software agent is important that acquires domain knowledge and represents acquired knowledge. The multi agent system, which is consisted of many independent agents system by their cooperation used to solve more complicated system [1]. Fig. 2 shows configuration of multi agent system. When agents need to communicate to each other, they use KQML (Knowledge Query and Manipulation Language). The KQML provides a framework for programs and agents to exchange information and knowledge [3].

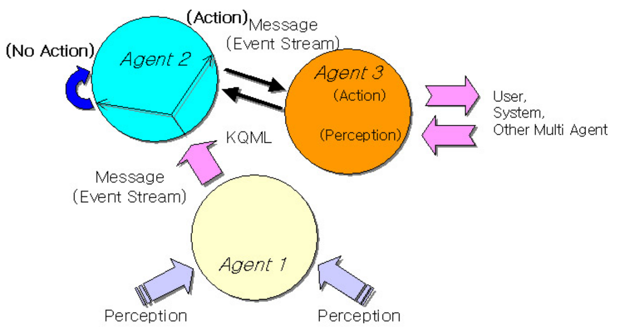


Fig. 2 The configuration of multi-agent system

The intelligent machine tools based on agent is consisted of sensory agent that acquire the condition of machine tools, dialogue agent that communicate with other machines, decision support agent that support operators or machines to make very well optimal solution based on accumulated knowledge. They communicate according to standard agent communication protocol [3].

3 Decision Support System

3.1 Construction of domain knowledge

The decision support agent accumulates direct or indirect knowledge arisen from machine tools and presents the reasoned results by communicating with sensory agent and dialogue agent to operators or other machines [2]. We can classify the knowledge from machine tools that are machine-dependent knowledge and machine-independent knowledge. The machine dependent knowledge is vibration of a structure, feature of thermal error, cutting feature and so on. This knowledge is used to only self machine tools. The machine-independent knowledge is that is process knowledge, ability of operation, cutting condition, etc. This knowledge is applicable to general machine tools [6].

In this study, the knowledge of developed decision support agent is consisted of the machine-dependent knowledge that compensation the thermal error and the machine-independent knowledge that suggest cutting condition according to the feature of work piece and processing method.

Table 1 shows the relation between the domain knowledge made-up by decision support agent and the related agents [5, 7].

Table 1 Knowledge of decision support agent

	Domain knowledge	Agent	Link
Machine Dependent Knowledge	Compensation Thermal error	Sensory	On-line
Machine Independent Knowledge	Cutting condition According to Material's feature & How to processed	Dialogue	Off-line

The knowledge divided by above table is gained by using the thermal error model from thermal experiment based on previous research and cutting condition of each tool from technical data provided by toolmaker and Machining Data Handbook. The knowledge base is constructed by using rule base system if ~ then ~ formation. If ~ then ~ rules have become the most popular form of declarative knowledge representation used in AI application. If ~ then ~ rules are easily understandable. The rule is consisted of an antecedent clause and consequent clause. Each rule can be viewed as a standalone piece of knowledge or unit of information in a knowledge base. New knowledge can be easily added, and existing knowledge can be easily modified. We use the inference method that is made up by combination of forward chaining and backward chaining [6]. Forward chaining is a data-driven reasoning process in which a set of rules us used to drive new facts from an initial set of data. Forward chaining is very fast and also used in real-time monitoring and diagnostic system. Backward chaining is often called goal-directed reasoning, because a particular consequence or goal clauses is evaluated first, and then we go backward through rules. Backward chaining is used for advisory expert system.

3.2 Decision Support Agent composed by module

When the basic construction of agent s explained, the word module or model is used to mention. The module is something that for agent to work, and the model is the method to realize the module as shown Fig. 3 [4].

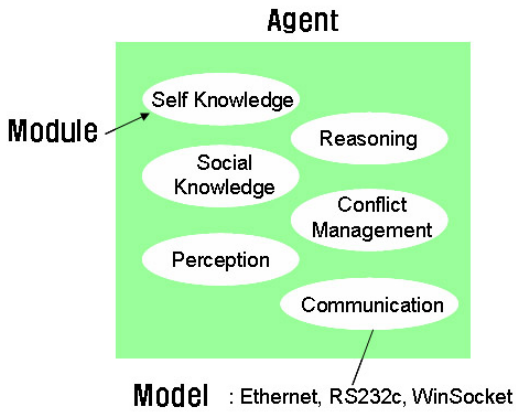


Fig. 3 The structure of agent

Fig. 4 shows the construction of decision support agent composed by module.

It is consisted of the reasoning module which manages data and knowledge acquired to the activities of agent, the perception module which recognizes outer circumstance, the interpreter module which interprets the signal from communication module, the social knowledge module which has information about other agents, and the communication module which communicates with other agents. The reasoning & inference and rule engine module infers an unknown fact from rule base.

The commercial inference engine is used in this research for constructing rule base mentioned on prior chapter, because the reasoning program that programs general reasoning methods can be slowed down when there are many rules to process and the reliability of reasoning results is not convinced. The inference engine used in this research has very strong reasoning ability that forward chaining and backward chaining are included in it and can apply them at the same time. Also, it can process 10,000 rules per second by applying rete algorithm method. Especially, it is all on java structure so the agent could be realized easily by using outer java classes and API.

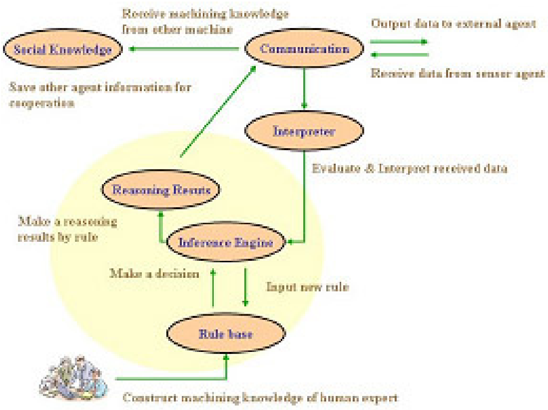


Fig. 4 Construction of decision support agent composed by module

4 Application

4.1 Compensation of thermal error

The errors happened from machine tools are classified into static error and dynamic error by the feature of errors. The dynamic error is that is from vibration and chatter of machine tools and vibration of units of spindle. The static error is classified into geometry error which is from feature of assembly like inner surface, column, ball screw and thermal error. Especially, thermal error is important factor of accuracy of machine tools and it is about 70% of total error of machine tools [7]. For the application of the developed system, we made up rule base of thermal error based on prediction model using multi factor regression analysis model and implemented it onto PC-NC controller. The measuring model of the displacement of thermal error according to temperature change follows ISO/DIS 203-3, BS3500:part3:1900 and ASME B5.54-1992.

Fig. 5 is the experiment of thermal displacement to acquire the change of temperature and displacement. Thermocouples are adhered to the front of spindle and upper and lower of y axis. The eddy current sensor is used to measure real displacement as shown Fig. 5.

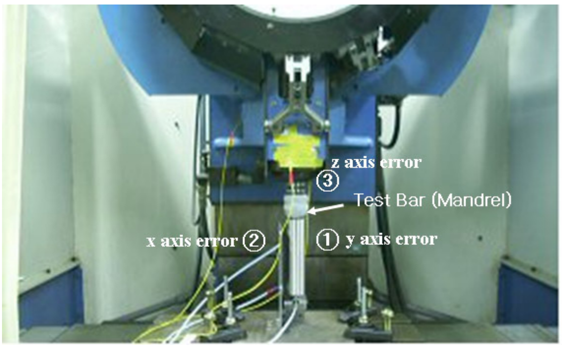


Fig. 5 The experiment of thermal error

To construct the prediction model of thermal displacement, we made the experimental machine tools and revolve spindle at 4000rpm, 6000rpm, and 5000rpm each for 4 hours with non-loaded condition. And then it is cooled for 12 hours. Fig. 6 shows the displacement of z axis over time.

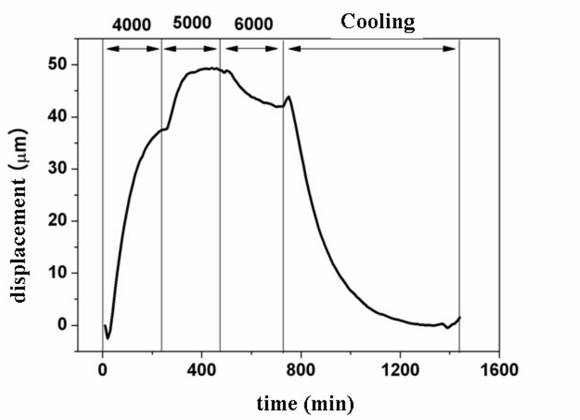


Fig. 6 The displacement (z axis) over time

We check the temperature every 10 minute at that time and predict displacement and make rule base about the compensation of thermal error.

Fig. 7 shows the application of compensation of thermal error using developed decision support system. The system receives temperature value from the thermo couple sensors which are on each axis (3 point) and then provides predicted compensation value to operator from constructed rule base of thermal error compensation.

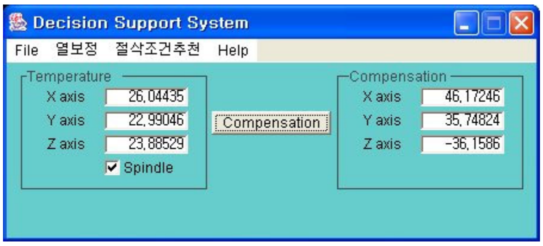


Fig. 7 Screen for compensation of thermal error

The compensation of thermal error is classified into manual compensation at that time and auto compensation which uses the method that predicting compensation value on each time interval. The error of thermal displacement is compensated by modifying offset value by operator. As a result of comparing the real displacement provided by eddy current sensor and predicted value provided by rule base of thermal error compensation, about 96% as average the accuracy is gained as shown Fig. 8.

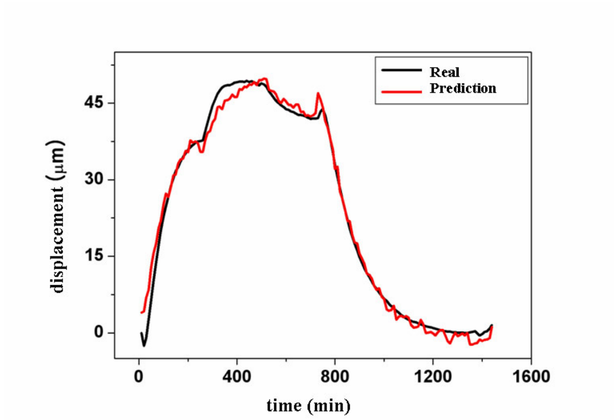


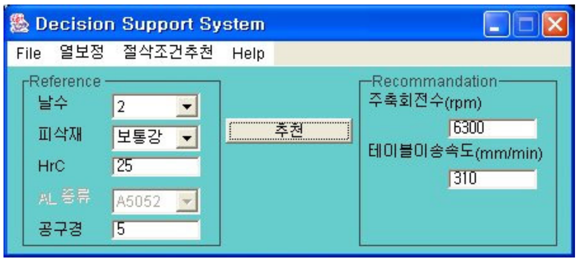
Fig. 8 Compare the real and prediction displacement

4.2 Recommending cutting condition with material's feature and processing method

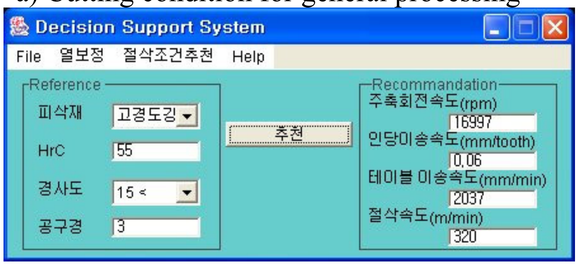
The companies which produces die & mold make an effort to produce die & mold economically as fast as possible as there is a variety of product and shorten life cycle recently. In case of making die & mold, generally 1,200~3,800 hours are spent to make it, vary with size, shape and complex. The 35~55% of total processing time is spent on the NC processing.

The cutting condition is very important factor to determine processing time, and affect on the processing accuracy and the durability of tools [5]. Therefore we constructed rule base that has cutting condition rule on the constructed decision support system and applied the system that recommend the optimal cutting condition with features of materials and processing method.

We classified the recommendation of cutting condition according to how to process such as into ball end-mill, drilling and so on. In the case of the ball end-mill, it is classified into for high-speed processing and for general processing so that it recommends the cutting condition.



a) Cutting condition for general processing



b) Cutting condition for high-speed processing

Fig. 9 The recommendation of cutting condition

The most general cutting method used in the producing die & mold id end-mill processing. In the 3D processing that include complicated curves or incline plane, the ball end-mill is used. Fig. 9 shows the cutting condition of ball end-mill that has 2 teeth. As inputting the feature of material with hardness (H_RC), the gradient of processing surface (15º as origin) and the diameter of tool, there could be a recommendation of the revolution per a minute (RPM), feed per tooth (mm/rev), the cutting speed (m/min) and feed per one minute (mm/tooth).

5 Conclusion

In this study, we classified the knowledge used in machine tools into machine-dependent knowledge and machine-independent knowledge. And as a representatively machine-dependent knowledge we constructed the rule base of compensation of thermal error and as machine-independent knowledge we constructed the rule base that recommend cutting condition with feature of material and processing method. In order to implement developed system on open controller (PC-NC) of machine tools, we designed and realized decision support system based on agent, and applied to real system with constructed rule base. The developed and proposed system would be important factor for realizing intelligent machine tools and would be extend to a system that include the intelligent agent communication in M2M (Machine to Machine) environment that would be come true later.

Acknowledgement

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