

Intelligent Open CNC System Based on the Knowledge Server Concept

János Nacsa

(nacsa@sztaki.hu)

Computer and Automation Research Institute (www.sztaki.hu)

Budapest, Hungary

Abstract: In an ideal scenario of intelligent machine tools [18] the human mechanist was almost replaced by the controller. During the last decade many efforts have been made to get closer to this ideal scenario, but the way of information processing within the CNC did not change too much. The paper summarises the requirements of an intelligent CNC evaluating the different research efforts done in this field using different artificial intelligence (AI) methods. In the second part of the paper a low cost concept for intelligent systems named Knowledge Server for Controllers (KSC) is introduced. It allows more devices to solve their intelligent processing needs using the same server that is capable to process intelligent data. In the final part this concept is used in an open CNC environment to build up an intelligent CNC. The preliminary results of the implementation are also introduced.

Key words: intelligent CNC, knowledge server, open systems

1. INTRODUCTION

There are many definitions of the intelligent machine tool in the literature. In a well known book [18] Wright and Bourne said that „*We must therefore acknowledge that the degree of intelligence can be gauged by the complexity of the input and/or the difficulty of ad hoc in-process problems that get solved during a successful operation. Our unattached, fully matured intelligent machine tool will be able to manufacture accurate aerospace components and get a good part right the first time*”. They told that an intelligent machine tool had the CAD data, the materials and the set-up plans as inputs and could produce correctly machined parts with quality control data as outputs.

It is clear that AI techniques are necessary to apply if one wants intelligent NC machine, but - of course - the usage of them is not adequate in intelligent behaviour.

Table 1 summaries the features of an intelligent CNC (Wright and Bourne collected them more than ten years ago) and shows two further things: the positive changes done in the recent years and the still existing gaps where - according to the scientific community - AI offers solutions with its information processing methods.

Table 1. Commercial needs for the intelligent machine tools

Features (forecasted in 1988)	Big advance by 2001	AI methods still needed
Reduce the number of scrap parts following initial setup.		✓
Increase the accuracy with which parts are made.	✓✓	✓
Increase the predictability of machine tool operations.	✓	✓
Reduce the manned operations in the machine tool environment.		✓✓
Reduce the skill level required for machine setup and operations.		✓✓
Reduce total costs for part fabrication.	✓	✓
Reduce machine downtime.	✓	
Increase machine throughput.	✓✓	✓
Increase the range of materials that can be both setup and machined.	✓	
Increase the range of possible geometries for the part		✓
Reduce tooling through better operation planning	✓	
Reduce number of operations required for setup	✓	
Reduce setup time by designing parts for ease of setup	✓✓	
Reduce the time between part design and fabrication	✓✓	
Increase the quantity of information between the machine control and part design operations	✓✓	
Increase the quantity of information between the machine operations and the machine control		✓
Increase the quantity of information between the human and the machine control	✓✓	✓

Analysing the above list, it is clear that many features do not require direct AI methods. We can state that the main reasons of the advancement were:

- (1) the development of the hardware elements (more sensitive sensors, more precise actuators, quicker and stronger computers etc.) even in higher requirements.
- (2) The development of the software and the methodology mainly in the preparation phases of the manufacturing (in design, planning, scheduling, resource management etc.) and in the user interface issues (more comfortable and informative 'windows-like' screens and menus).

Even there is a big advance in the technology of the CNCs, the knowledge processing and other AI methods have not appeared within the

controllers, so in some points there is no real development. Special heuristic rules, problem-solving strategies, learning capabilities and knowledge communication features are still missing from the recent controllers available on the market. It is also true for many new, open or PC-based CNCs, where DSP add-on-boards provide the necessary computation power and speed.

Further requirements of intelligent CNCs can be found and defined (Table 2.): based on other papers [9,10,16] and different discussions. The second column indicates whether the different AI techniques (mainly rule base systems, neural nets and fuzzy logic) would provide methods and solutions. One can find positive answers to all these issues in the recent literature:

Table 2. Future requirements of an intelligent CNC

Further features	AI would help
Model based on-line path generation	(✓)
Automatic tool selection	✓
Technological based settings of the operational parameters	(✓)
Automatic compensation of machine limits	✓
Automatic back-step strategies	✓
Detection and compensation of geometrical deflection	✓✓
On-line selection of control algorithms	(✓)
Intelligent co-operation with other devices to solve problems together	✓
Detection and correction of tool wear and breakage	✓✓
Automatic handling of rejected workpieces	✓✓
Detection and managing of emerging situations of the machine tool	✓✓
Complex self-diagnostics	✓✓

The list may be continued with the learning capabilities and others. In the users' point of view these features rough in a controller, that "recognises the problem" and "efficiently and reasonable solves them" with minimal disturbance of the environment of the controller.

2. RESULTS IN INTELLIGENT CNCs

On the one hand (1) in the recent literature one can find many different topics related to intelligent CNCs. Unfortunately they often do not mean intelligent behaviours but the application of intelligent methods. Sometimes it is the case that authors call their devices "intelligent" if one module of the system contains AI based method. On the other hand (2) the key controller vendors leave everything to the users or machine tool builders offering PC/Windows based CNCs. With these systems any software modules (e.g. even AI based ones) can be coupled into the controller but they do not offer

real solutions or methodologies, but only software possibilities. Both facts are far from the user wishes stated in the previous chapter.

The following list summarises the most important active research topics in this field. A real intelligent CNC would contain most of these issues.

- Fuzzy logic based concurrent control of some operating parameters (e.g. cutting speed, depth of cut, feed rate) independently from the given tool and the workpiece.
- Neural nets and fuzzy rules in the CNC's control algorithms.
- Optimal path planning, real-time correction of the trajectory.
- Compensation of temperature (and other) deformations.
- Life time management of the tools and other parts of the machine tool including self-diagnostics.
- Tool breakage detection (maybe forecasting) and tool wear monitoring (maybe compensation) with AI methods.
- The utilisation of CNC management (setup, orders, etc.) via intelligent agents.

Monostori [9] classifies the possible intelligent parts of a CNC into three groups, namely: (1) tool monitoring, (2) operation/machine tool modelling and (3) adaptive control.

A general problem in all the three groups is, that the AI based solutions are typically limited and valid only in a very narrow field. If one changes some parameters of the operation or the environment, the earlier successful methods become false.

A special type of adaptivity partly helps on this hard and well-known problem. If it is possible to replace the different modules of the controller time by time, than one can guarantee, that a given AI module can run within its limitation, and over it another module (e.g. a much simpler one) covers the same functionality. It can be realised (among others) if the controller is open to allow this replacement.

There are some research efforts where more than one intelligent modules are built into the controller. So Cheng et al. [3] developed a PC based controller where some DSP cards serve intelligent functions (e.g. adaptive control of cutting force using fuzzy logic; knowledge based self-diagnostic and error recovery/management; multisensor based neuro-fuzzy tool monitoring).

3. OPEN CONTROLLER INITIATIVES

Manufacturing has constantly been a technological domain, in which the industry was driven to apply the current high-tech in the computer and control area. It is no surprise, that the Open Systems concept has also

diffused into the manufacturing area, and factory managers are often referring to the open manufacturing systems. The terms and definitions are far less exact than the terms applied in the operating systems environment, but by now, the change of the global manufacturing paradigms (e.g. see Kovács [7]) are directing our focus on the key user aspects of openness.

The need for a new and open CNC architecture was emerging at many places around the world. One of the most important work was done from 1992 within the frames of the European project named OSACA (Open System Architecture for Control Applications) [15]. The main results of the project are: an analysis of the state-of-the-art and future requirements of NC controllers, a reference architecture, a general and platform independent API for inner CNC and outside communication and a configuration system supporting the possible machine tool vendors. Similar efforts are going on in Japan under the IROFA Consortium [14] and in the U.S. within the OMAC projects [13].

In all these projects the module structures and hierarchies (reference architecture) of the NC controllers and the APIs of any defined modules were published. Unfortunately even if the aims of these efforts are nearly the same the resulted controllers are incompatible in many sense [12]. But because of the open modules and the precisely defined APIs, any of these efforts could be a very good starting point of building intelligent CNCs. It is possible to implement any modules of the reference architecture using AI methods or to add further advanced modules to provide extra features for the controller.

4. DIFFERENT APPROACHES OF KNOWLEDGE SERVERS

The features of World Wide Web led Eriksson [5] to introduce knowledge server to easier solve the installation and version control problems of expert systems and to provide a web based interface of the knowledge base for the different users.

Some advanced knowledge based systems are based on this concept. So the Cyc system, the most important research on the common sense, is organised as a knowledge server [8]. Also the Istar knowledge server [1] provides on-line advises in many different topics (e.g. stock exchange, Internet security). There are also some applications of knowledge servers in manufacturing (e.g. Váncza at al. [17] uses it in a robotic inspection planning system).

In the HPKB (High Performance Knowledge Environment) [4] some hundred thousand rules are performed in an intelligent knowledge

environment. In this project the different intelligent components are called knowledge servers. The components are communicating with each other via the OKBC (Open Knowledge Base Connectivity) protocol [2] specified at Stanford.

5. KNOWLEDGE SERVER FOR CONTROLLERS

Knowledge Server for Controllers (KSC) is defined as a server providing capability of intelligent data processing for other systems. It allows the basic system to reach external intelligent processing resources, because it does not have any. The KSC contains a high performance reasoning tool, and different knowledge based modules. All the modules have their special rules and procedures. The client system calls these modules, passes them specific data if necessary, and the KSC module can collect data if the knowledge processing requires. All the data acquisition and user interaction is done by the client system. It is clear that in KSC the clients have much more tasks than a simple browser based user interface and in the applications listed in the previous chapter.

It should be stated that KSC does not deal with fuzzy and neural net based AI modules. The computing power and the necessary software costs and complexity of these methods are less than the rule or model based ones. (In the case of the neural nets it is true only if the net is not trained on-line.)

The KSC allows the different modules to run independently, to cooperate as agents or to control each other. The third case means that one module is started by another one because either the second one uses the results of the first one or the inference of the first one led to the need of the second module.

Generally the resources of the KSC can use more clients (controllers or SCADA systems) simultaneously. It leads to a cost effective AI solution, because one costly AI tool can solve all the intelligent problems in a distributed environment. The overhead of the KSC (network connection, one more computer, some delay etc.) is much less comparing to the advantages (AI tool licensing, less computing power in the clients/controllers, one server module may be used by more clients etc.).

Using the KSC together with the component based software technology (e.g. CORBA) gives a very adaptive software frame to solve complex problems.

In the Fig. 1 a CNC with an embedded PLC controls a machine tool. The modules of both controllers are open and some of them are also clients of a knowledge server (KSC). It means that these modules can run special AI

methods during their work that is an independent service is implemented in the KSC.

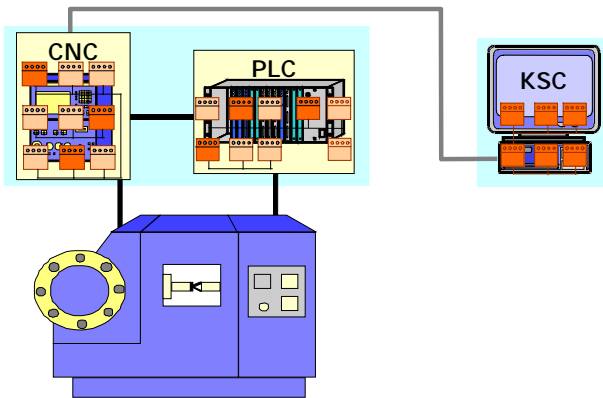


Figure 1. Intelligent CNC using KSC

6. PROTOTYPE INTELLIGENT CNC BASED ON KSC

In an early prototype of the intelligent open CNC that is using KSC, the axis module (Fig. 2) was implemented based on the OMAC module specification [13]. As a basic configuration the OMAC *Axis* module uses two *ControlLaw* modules to have position and velocity control over the real axis that is reached via the *IOPoints* module. The *Axis* is manipulated from the *AxisHMI*.

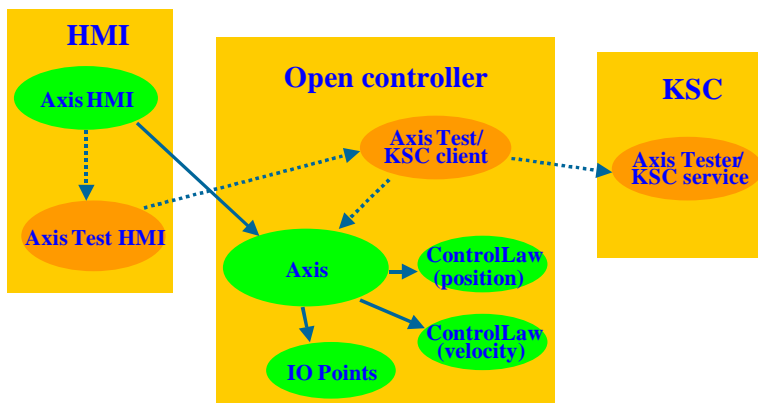


Figure 2. Intelligent tester of a machine tool axis

An advance axis tester is put on the top of this. *AxisTest* module handles all the tests but it gets the necessary position and velocity values from a knowledge based general tester running as an application on the KSC.

The KB tester determines some goal positions and motion speeds, that the *AxisTest* module executes with the axis using jog commands. The results (execution time, tuning in errors etc.) are sent to the KSC that analyses and qualifies the axis.

In the prototype the modules are built in CORBA, the controller and the HMI is programmed in Java, while the KSC is based on G2 environment [6].

7. CONCLUSIONS

The different research results and the open problems of intelligent CNCs were shortly introduced. It was stated that many wishes from the 80's are still unsolved and many of the existing open issues claim AI solutions.

The features of the open controllers were also summarised with the most important open system controller initiatives.

The knowledge server concept of Eriksson was introduced in the field of controllers with some important modifications comparing with the original idea. The features of KSC were discussed and an early prototype (axis tester) was introduced. Further works are going on to develop a complete intelligent CNC for a 3D milling machine using KSC.

It should be mentioned that a KSC was successfully implemented in an advisory system of an electrical substation of a nuclear power plant [11]. In this application the KSC was connected to a SCADA system and it supported 5 different intelligent functions.

8. REFERENCES

- 1 Basden A: The Istar Knowledge Server, (2000)
<http://www.basden.u-net.com/pgm/Istar/index.html>
- 2 Chaudhri F. V., R. Fikes, P. Karp, J. Rice. (1998) OKBC: A Programmatic Foundation for Knowledge Base Interoperability. Proc. of AAAI-98,
- 3 Cheng, T., J. Zhang, C. Hu, B. Wu, S. Yang (2001) Intelligent Machine Tools in a Distributed Network Manufacturing Mode Environment, Int. J. Adv. Manuf. Technol. 17:221-232
- 4 Cohen Paul R., Robert Schrag, Eric Jones, Adam Pease, Albert Lin, Barbara Starr, David Easter, David Gunning and Murray Burke. 1998. The DARPA High Performance Knowledge Bases Project. In Artificial Intelligence Magazine. Vol. 19, No. 4, pp.25-49
- 5 Eriksson H: Expert Systems as Knowledge Servers (1996) IEEE Expert, Vol. 11, No. 3
- 6 Gensym (2000) A Strategic Choice for Improving Business Operations: G2 Classic,
<http://www.gensym.com/products/g2.htm>

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- 7 Kovács, G. L. (1996) Changing Paradigms in Manufacturing Automation. Proc. of IEEE International Conference on Robotics and Automation, Minneapolis, USA, Vol. 4. pp. 3343-3348
- 8 Lenat, D: CYC: A Large-Scale Investment in Knowledge Infrastructure, Comm. of ACM, 38(11) pp. 33-38, 1995; + Cyc Knowledge Server:
<http://www.cyc.com/products.html>
- 9 Monostori L. (2000) Intelligent Machines, Proc. of 2nd Conf. on Mechanical Engineering, Budapest, Hungary, May. 25-26, pp. 24-36
- 10 Nacsa J, G. Haidegger (1997) Built-in Intelligent Control Applications of Open CNCs, Proc. of the 2nd World Congress on Intelligent Manufacturing Processes and Systems, Springer, Budapest, Hungary, June 10-13., pp. 388-392
- 11 Nacsa J., Kovács G. L. (2001) Alert State Detection and Switching Order Generation at a 400/120 kV Substation using Knowledge Server, ISAP2001 Conference. (Intelligent Systems Application to Power Systems), Budapest, 18-21 June
- 12 Nacsa J. (2001) Comparison of three different open architecture controllers, IFAC MIM, Prague, 2-4 Aug.
- 13 OMAC API Work Group (1999) OMAC API SET, Version 0.23, Working Document,
<http://www.isd.mel.nist.gov/projects/omacapi/>
- 14 OSE Consortium, (1996) OSEC: Open System Env. for Controller Architecture Draft,
<http://www.mli.co.jp/OSE/>
- 15 Pritschow, Sperling (1994). Open System Controllers - A Challenge for the Future of the Machine Industry. CIRP Annals
- 16 Teti R, S. Kumara (1997) Intelligent Computing Methods for Manufacturing Systems, Annals of CIRP, Vol 46/2, pp. 629-652
- 17 Váncza J., Horváth M., Stankóczy Z.: Robotic Inspection Plan Optimization by Case-Based Reasoning, Proc. of the 2nd World Congress on Intelligent Manufacturing Systems and Processes, June 1997, Budapest, Hungary, pp. 509-515
- 18 Wright P.K., D.A. Bourne (1988) Manufacturing Intelligence, Addison-Wesley

9. BIOGRAPHY

János Nacsa received his diploma degree in electrical engineering from Technical University of Budapest in 1987. Since that he is a research associate of the CIM Laboratory of the Computer and Automation Research Institute, Budapest, Hungary. He published more than 50 papers and led different research projects. His research topics are open systems and application of artificial intelligence in manufacturing.