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Scalable open cross-platform kernel of PCNC system for multi-axis machine tool

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Abstract

Creating the basis of numerical control is demanded by ensuring the invariance of the applied solution, reducing the development cycle and preserving investments made in software development through cross-platform solution for real-time, the component approach and code reusing. Open architecture is implemented with the help of allocating the levels of abstraction in the CNC kernel, which provides transparence kernel algorithms according to the specifics of the hardware solution, the flow program language version, and the way of implementing the operator interface. The paper illustrates the approach of the invariant CNC kernel layout and the scaling of the control channels inside the pipeline data processing, according to the multi-axis machine requirements. The prospects of development in the direction of using web-technologies and creating remote terminals for controlling, monitoring and adjusting machine tools are defined. The right choice of the control system architecture reduces the interpolation and PLC cycle time, which is the determining factor in the high-speed cutting for multi-axis machine tools. It results in reducing data processing time in CNC enhance the manufacturing performance.

Keywords: CNC system with open modular architecture; pipeline processing of a flow program; remote terminal

1. Introduction

CNC system defines the foundation of modern industrial technology. Their implementation requires a control system with an open modular, scalable architecture and a portable kernel [1].

Analysis of the world leaders NC systems FANUC Series 30i/31i/32i-MODEL (FANUC, Japan), SINUMERIK 840D/Di (SIEMENS, Germany), iTNC-530 (Heidenhain, Germany), MTX Advanced (Bosch Rexroth, Germany), M750 (Mitsubishi, Japan), CNC 8070 (FAGOR, Spain) and etc., allowed to identify the key features of «Hi-End» modern control systems:

- multi-axis machining and multi-channel control (up to 64 axes at 10-12 channels);
- the functions of artificial intelligence to compensate the temperature deformations and the monitoring and predicting the tool life;
- HPC (High Performance Cutting) and ultra precise machining with application of nano-interpolation and look-ahead algorithms;
- functions of spline interpolation and NC block compression, adaptive feed control, 3D processing visualization and verification mechanical collision of the machine tool, fixture, workpiece and cutting tool;
- system support of shop floor programming and programming in a high-level language;
- remote diagnostics, monitoring and supervising of the CNC system, networking opportunities to combine multiple CNC systems into complex systems based on the Ethernet;
- energy efficiency.

It is worth noting that the development in general is estimated in thousands of person-years and manufacturers are producing more and more new and improved versions with advanced functionality [2]. The development of control systems requires a significant investment and the availability of powerful scientific and

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engineering capabilities, but even more important is to define the concept of development.

Today the complexity of modern control systems has reached such that it is becoming impossible to master all the new software developments unless one applies-rigorous structuring and methodologies. The component approach makes breaking down complex software applications into independent and controllable autonomous components [3]. The notion of a component interface allows real separation between the use of a component and its implementation.

The concept of creating Hi-End CNC system supposes the formation of cross-platform solutions in real time, using the component approach and provides opportunities for code reuse. Main ideas of concept can be formulated as follows:

- In-house decision will allow implementing without any restrictions new innovative projects based on the Hi-End CNC with an open modular architecture.
- Using an industrial PC-platform will support the extensive set of peripherals and most powerful development tools and diagnostic software, will provide a wide range of software and hardware solutions and components on the market for integration into the control system.
- The orientation to standard equipment will reduce the cost of development and time-to-market, increase system reliability and maintainability of the product.
- Use of the modular approach allows configuring the CNC system for specific applications in different price categories [4].
- Reuse of code will reduce development time and will provide visibility and reliability of the software.
- Cross-platform solution allows to transfer the software of CNC kernel on different platforms and preserves the investments if new perspective developments in hardware and operating systems appear [5].
- The openness of architecture [6] and the modular approach allow machine builders and end users to integrate their know-how in the area of high-speed cutting technology, including special canned cycles, interpolation algorithms, kinematic transformations, adaptive management and etc. in the CNC system.

The openness of CNC systems on the market, is mainly declarative, or has rigid restrictions. Most often openness is seen as the opportunity to create custom screens and input masks, adjusting embedded in the kernel mechanisms (eg, electronic gearbox), at least - as an opportunity to add your own interpolation algorithms. Such manufacturers as Fanuc and Heidenhain only sell complete control systems with servo drives and cycle logic. The same direction keeps Siemens with its latest product - solution line and hardware integrated servo drive controllers in the CNC system. Bosch Rexroth uses similar integrated solution only for low-cost control system - IndraMotion MTX micro. The necessity to create a scalable cross-platform open CNC kernel is defined as follows:

- new research solutions in the area of process equipment, when required level of CNC openness is not defined;
- a small production of machine tools, where for a few instances nobody will adapt serial CNC systems;
- the need to ensure decisions, when the proposed level of openness is not sufficient, and the purchase of the next one is unreasonable;
- use of existing developments with third party equipment that are not always integrating in a standard CNC system.

2. Cross platform base kernel

A control system as a virtual machine has a multi-layered structure (Fig. 1), the lowest level is a standard industrial PC-hardware and specialized NC-hardware for the process equipment connected through fieldbus. Together with real time operating system, part of the next level, they form a platform of control system. At present the operating systems Linux RT, Windows RTX (real time extension from Interval Zero) are used. On both operating systems the main process is performed with time slice 100 µs. For the test mode and the tasks, which do not require a high performance, such as hydraulic test stands, the version based of Windows with the main process time slice 1 ms is used.

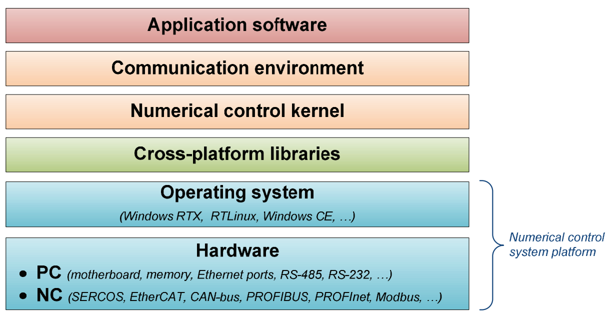

Fig. 1 - Cross-platform implementation of control system

The platform-independent layer, located above, masks the specific of the platform from the upper levels of the software implementation. Timers, mutexes, shared memory, wrappers of the Run Time Library functions and other elements that are specific for each operating system are implemented in that layer.

The part program interpreter, interpolation algorithms, the algorithm look ahead, algorithms for the kinematic transformation, SoftPLC and cycle logic control algorithms, also task scheduling are implemented on the layer of kernel.

The level of communication environment provides information exchange between the control system kernel and application software, regardless of the architectural organization (two-or onecomputer solution) [7].

The interface of the operator of the machine tool, the editor of flow programs, the machine parameters editor, terminal part of the special diagnostic applications, for example, a digital oscilloscope, logic analyzer or a subsystem for monitoring and tool life prediction are located at the application level [8]. Most of these applications are implemented on the platform .NET, but solutions based on web-browser can be applied, such as remote terminal of CNC system [9].

3. Pipeline data processing

Pipeline processing of flow program, written in G-code (ISO 6983) or in high-level program language, determines the sequence of calling modules in the process of work.

Architecture of pipeline data processing defines the level of CNC openness. It includes the kernel operating in real time (Linux RT) and a terminal part which operates in machine time and which is realized on OS Windows with platform .Net or a portable operator terminal based on Linux with limited functionalities (Fig. 2).

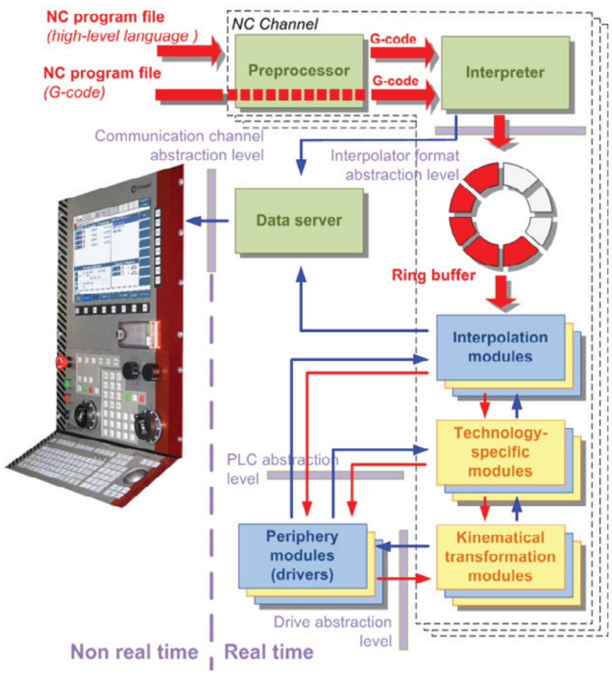

Fig. 2. Structure of the data processing pipeline

The flow program file in G-code or in the high-level program language is interpreted and the result is written into the ring buffer of prepared interpolator command, which allows to use look-ahead algorithm and to optimize the movement of executive mechanisms of the machine . The preprocessor is used in case of high-level language constructions, which based on the notation ANSI C. It works with local, global and system variables, loops, conditional and unconditional jumps, and so on. The preprocessor is transparent for flow programs in G-code and passes them through itself without any changing. Interpolator implements the basic types of interpolation (linear, circular, helical) and spline (Akima, cubic splines and NURBS).

The combination of spline interpolation with look-ahead algorithm allows using of certainly higher feed rate for the same accuracy of the part. For example, a flow program for a milling part with linear interpolation is executed for 780 seconds, a flow program with spline interpolation and look-ahead for the same part needs only 552 seconds, as a result the processing time is reduced up to 30%. Approximately the same test results were obtained with SINUMERIK 840D control system.

As a result of interpolation control commands for servo drives and PLC are generated. Information on the execution of flow program, the current state of servo drives and PLC are transmitted to the data server for displaying on the user interface. A special mechanism implemented in the data server optimizes traffic information exchange [10].

Technological modules are optional and they are used if the technology requires additional movement on the process of forming (generation of geometry) or in case of synchronization the motion control with such devices as industrial laser or electron-beam gun [11].

The kinematic transformation module converts the coordinates taking in consideration the kinematic scheme of the machine tool and the need to ensure constant contour processing speed. Using of concrete kinematic transformation module is determined at the stage of settings NC machine parameters in accordance with the machine tool kinematics.

The openness of control system architecture is concentrated in the levels of abstraction, which ensures the kernel independence from the shared level specific implementation. Abstraction on the level of the interpreter allows using any description language for the workpiece processing to transfer data in the interpolator.

Abstraction at the communication channel level is implemented with the help of streaming data and provides connectivity to the kernel data server multiple terminal clients, including those connected via Internet remote terminals.

Abstraction at the level of drives and PLC ensures the independence of the control system kernel from the field bus interfaces of drive controllers and PLC. Additionally, it allows using the same interface (for example, CANopen, SERCOS-III or EtherCAT [12]) for the PLC and the servo drive controllers.

Regardless of the kind of software and hardware COST (Commercially available Off-The-Shelf) or in-house developments, there is a problem of their integration into the control system, and the determining factors are: openness of architecture of control system, used technologies and the availability of standardized interfaces for embedded devices.

4. Invariant layout design of control system

Modern technological processes require a distributed work of managed components what is carried through industrial networks [13]. Property of invariance implemented in CNC system allows to arrange the controlling peripheral devices through industrial networks SERCOS II and SERCOS III, Step/Dir, CanBus or USCNet. In the case of using an external PLC interaction with kernel is done with help of fieldbus RS-232 or RS-485 (Fig. 3).

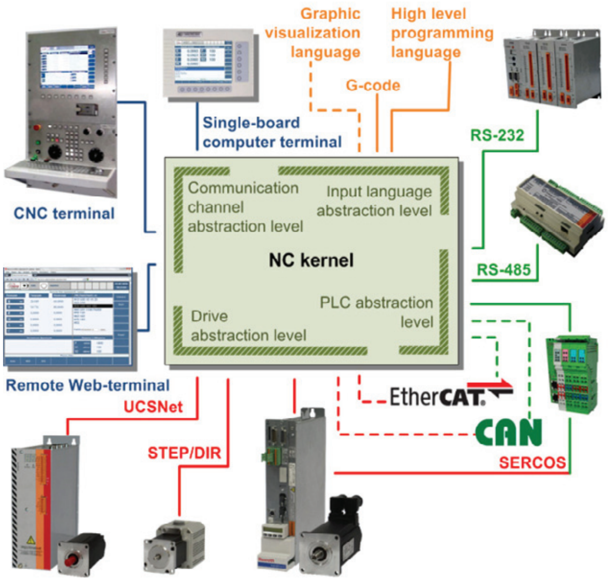

Fig. 3. The invariance of arranging the control system

A solution based on the built-in kernel soft PLC is used for machine tools with not sophisticated electromechanical equipment. In that case the inputs and outputs are implemented on a bus coupler with interface SERCOS III or EtherCAT. Commands to control outputs and status of the inputs are integrated in the cyclic data of drive control and they are transferred through the same interface.

The remote terminal connected via TCP/IP allows the operator to monitor the machine tool using a simplified HMI. The service department remotely diagnoses and configures digital drives according to the machine tolerance with the help of the web-terminal.

As an example, a version of arranging CNC system for the five-axis grinding machine with an additional high-speed spindle for internal grinding is illustrated (Fig. 4). The control system is implemented in one-computer version with two PCI expansion boards (SERCOS-Master card and multiport card). High-speed spindle is controlled via Memobus. Servo drives are connected to SERCOS-ring [14]. Bus coupler and expansion modules are also connected in this ring.

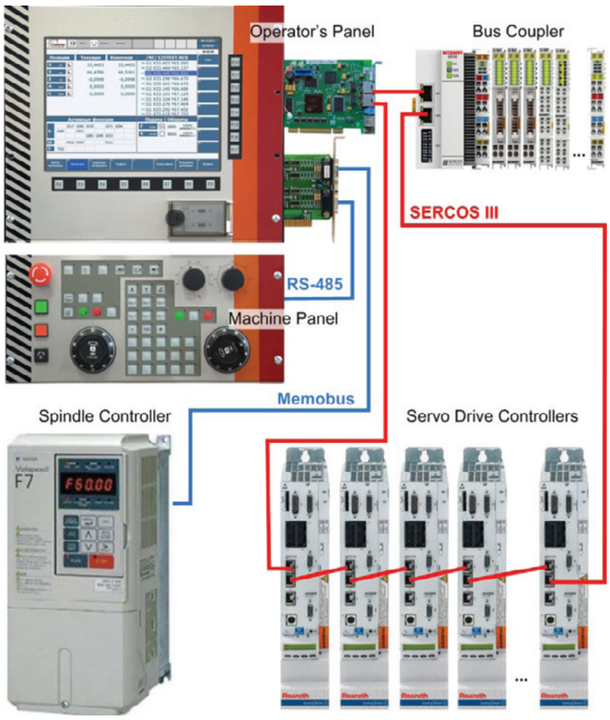

Fig. 4. Variant of CNC architecture layout for grinding machine

The proposed solution is based on a multi-protocol control system and allows to combine hardware and software components from different manufacturers.

5. Remote terminal

The organization of distributed control of components is carried out by incorporating them into a common information-computing environment through industrial networks. Large multi-axis machine tools are often equipped with several terminals, including portable operator console [15]. The importance of the problem of control, monitoring and diagnostics machine tools via remote terminal is increasing constantly. Web-server is developed and integrated into the CNC system (Fig. 5) [16]. It allows remote clients to work on personal computers, tablet PCs, smart-phones and other terminals to display the operator screen and control the CNC system via the web-browser.

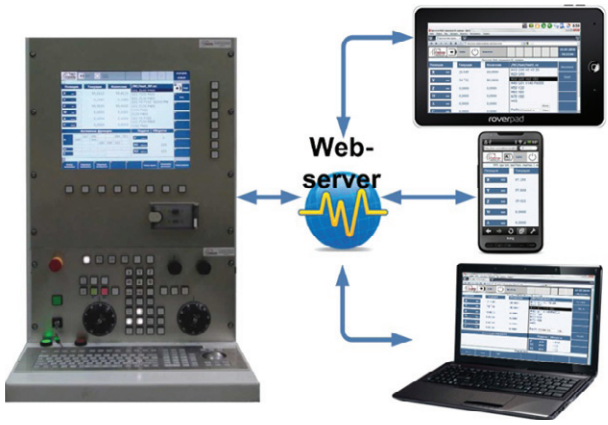

Fig. 5 - Prototype of CNC system with built-in web-server

The GUI of remote web-terminal, was developed with the help of web-based technologies and implements the basic functionality of CNC system like the main terminal [17]. The web-server provides a single receiving web-page through a browser, so there is no regular updates of the page, The dynamic displaying of change data capture during the operation of the machine tool is implemented base on AJAX technology, which allows modifying asynchronously the data on the user's web-page without reloading the whole page. The disadvantage of this technology is that not all mobile platforms support it, for example, the standard browser of Windows CE due to restricted functionalities. Manufacturers of CNC systems are using servo drives and PLC I/O equipment produced by them or their manufacturing partners.

The functionality of remote terminal increases on-line control and ensures timely the operator response during the processing of large parts.

6. Conclusion

Using a cross-platform kernel allows the control system software not to be dependent on the specific of platform and provides broad opportunities to configure the CNC system for multi-axis machine tools.

The world leaders spend 10-15 years for the development of each generation «Hi-End» CNC systems. The labour content of the development exceeds dozens thousand person-years, what determines the high price for the control system at this level. The price range of «Hi-End» CNC systems starts from 15 thousand Euros, this amount does not include the cost of servo drives, which means that the price of the complete system is significantly higher.

The proposed solution is based on a multi-protocol control system and allows combining hardware and software components from different manufacturers. Using a cross-platform kernel ensures the independence of the control system software from the specific of platform and provides broad opportunities to configure the CNC system for multi-axis machine tools.

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