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An Approach to Building a Multiprotocol CNC System

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Abstract—This paper examines the questions of multiprotocol realization of a computer numerical control system for heterogeneous technological complexes. The basic set of the industrial protocols of a CNC system is selected and substantiated. The authors propose the multiprotocol CNC system kernel architecture and reveal practical application aspects of the CNC system for turning and milling-engraving machines.

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1. INTRODUCTION

Nowadays, the market of industrial automation equipment is represented by a great number of companies, producing heterogeneous equipment and trying to realize a common control interface being an international standard. Numerous industrial standards exist both in Russia and abroad, which results in the control problem of various process equipment [1].

The development of a multiprotocol CNC system allows solving this problem for process equipment supplied with drives and different-type peripheral devices of Russian and foreign manufacturers. The multiprotocol solution approach provides the CNC system arranging for concrete process tasks in the best way.

The integration of different-manufacturer equipment into a CNC system is ensured by the property of openness. Today, the openness of the control system architecture rather represents a marketing trend than has any practical utility. A number of leading foreign manufactures of the CNC systems comprehend the openness of architecture as the end user's capability to create personalized displays of user's interface or, e.g., data input and retrieval masks. Other manufactures single out several levels of openness in the numerical control kernel; purchasing the maximum level of openness from available ones requires considerable costs. In practice, commercial systems provide limited openness, as they are oriented to the complete solution from one manufacturer (a CNC system, the controller of automatic electric actuators, and drives). Due to this circumstance, the development of a multiprotocol CNC system for the integration of heterogeneous equipment is an actual task nowadays.

As the base for the solution of this task, we have selected the CNC system *AxiOMA Control* designed at MSTU STANKIN [2]. The openness of its architecture is concentrated in the abstract levels which hide the hardware specifics of all devices and unify all resources from the viewpoint of control. This fact makes the control system kernel independent from the concrete realization of a shared level (see Fig. 1.). Abstraction at the level of drives and automatic electric actuators allows integrating heterogeneous equipment with different interfaces (CANbus, Memobus, SERCOS, EtherCAT and others) into a uniform system or using a same interface for the controllers of automatic electric actuators and drives [3].

The suggested approach guarantees the control system invariance with respect to the fieldbus used. There exist PCI or PCI-Express boards almost for all industrial interfaces (e.g., SERCOS

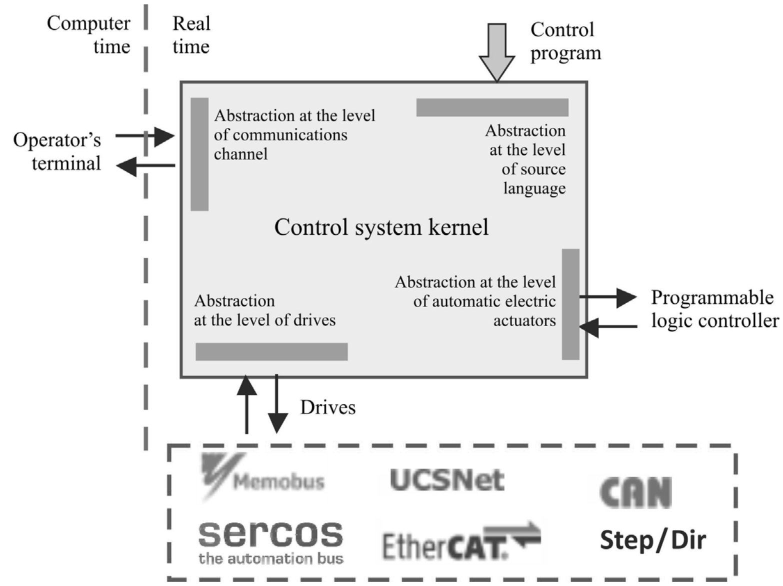

Fig. 1. The abstraction levels of the kernel in the CNC system *AxiOMA Control*.

III, PROFInet, EtherCAT and so forth). They make it possible to connect various devices to a computer. Moreover, multi-interface solutions appear with the feasibility of applying each of the mentioned protocols. Similar boards realize the interaction between the programmable driver and the digital drive controller.

2. ANALYSIS OF THE INDUSTRIAL PROTOCOLS USED IN CNC SYSTEMS

The variety of existing industrial protocols does not define the basic set of supported interfaces to-be-extended if necessary. A series of parameters, such as the mass character of manufactured devices, communication speed, the competitive prospects of protocols and others have been the key factors in choosing the basic set of fieldbuses supported by the CNC system *AxiOMA Control*.

Memobus is an industrial protocol developed by *Yaskawa* for the company's controllers. This is the modified Modbus protocol, and most data stored in the memory of *Yaskawa* controllers can be accessed by common Modbus commands. However, there exist some differences in addressing methods.

The master-slave communication model represents the basis of the Memobus network. The network has a master device which can be connected to maximum 64 slave devices. Data transmission is realized serially via the RS-485 interface with the maximum speed of 38 400 kbit/s.

UCSNet is an industrial protocol developed by MSUT STANKIN, originally for drives control of industrial robots. The second version of the protocol was adapted to follower drives control in CNC machines [4].

At the hardware level, the network is organized in the form of a fieldbus, which can be connected to 64 drives modules. Differential receivers and transmitters of the RS-422/485 standard act as network interface devices. Serial data transmission and receipt are realized by the universal asynchronous transceiver (UAT) protocol with the maximum speed of 1 Mbit/s. The minimum duration of a data exchange cycle makes up 0.139 ms.

CANbus (Controller Area Network) is an industrial network standard developed by Robert Bosch GmbH for networking different sensors and controllers of actuating devices. It employs serial data transmission in real time with high reliability and security [5]. Initially, this protocol was used in the automobile industry; later on, it was adopted in the area of industrial automation.

The basic characteristics of the industrial protocols

Parameter \ Protocol	SERCOS II	SERCOS III	UCSNet	Memobus	CANBus	EtherCAT	PROFInet
Physical layer standard	Optical fiber	Ethernet	RS-485	RS-485	RS-485	Ethernet	Ethernet
Network topology	Ring	Ring\bus	Bus	Bus	Bus	Ring\bus	Bus
Transmission speed (Mbit/s)	16	100	1	0.384	1	100	100
Cycle time (μs)	62.5	31.25	400	500	600	10	250
Number of nodes	256	512	64	64	128	65 536	255
Openness	Yes	Yes	Yes	Yes	Yes	Yes	Yes

A CAN industrial network represents a fieldbus built on the basis of the RS-485 interface. Data burst transmission is performed with the maximum speed of 1 Mbit/s, the minimum cycle time is 600 μs. In the original version, the standard included no application layer protocol. And so, different companies developed several such protocols, namely, CANopen (*CiA*) and DeviceNet (*Allen-Bradley*).

The SERCOS (Serial Real Time Communication System) interface is oriented to the development of distributed motion control systems. The differences between SERCOS II and SERCOS III are (a) the communicative fiber optics replaced by a twisted pair (the Ethernet technology) and (b) some extension of the interface [6]. SERCOS provides data exchange cycle restriction by the interface, guarantees precise synchronization of all coordinates' displacements, as well as assigns a service channel for noncyclic data exchange. SERCOS allows using different-manufacturer devices, regulating the standard for all parameters and commands transmitted in the system.

EtherCAT (Ethernet for Control Automation Technology) is an industrial network based on the Ethernet technology. It supports signals transmission, multicasting and slave devices communication. The EtherCAT slave devices realize data exchange during I-frame passage through a given node, thereby ensuring a fast exchange cycle. The EtherCAT I-frame contains data to-be-read and recorded by several devices simultaneously [7]. EtherCAT supports almost any topology and realizes the precision hardware-based synchronization of axes with a fast exchange cycle.

PROFInet is an open standard of Industrial Ethernet for automation systems. On the basis of PROFINET, engineers develop the systems of distributed input/output (PROFINET IO) where the controller implements communication with the peripheral devices.

Data exchange between the controller and input/output devices runs in real time. In the distributed systems of displacement and positioning control, data exchange takes place in real time with clock synchronization support (Isochronous Real Time). The data transmission speed in the network may reach 100 Mbit/s, and the exchange cycle time constitutes 250 μs [8].

The majority of the industrial interfaces not presented here are proprietor and can be used only in the complete supply conditions. Despite their formal openness, these interfaces were developed and are still controlled by a close range of manufacturers. The results of our analysis are combined in the table. For building a multiprotocol CNC system, we have selected the following basic interfaces:

CANbus (as a reliable and low-cost solution for medium-priced machines);

Memobus (as a simple and widespread solution in the field of spindle control);

SERCOS (as an acceptable solution for high-precision and ultrafast machining).

Considering the good prospects of the EtherCAT interface and its active market positioning in the recent 2–3 years, the specialists try to use the EtherCAT in a multiprotocol CNC system at the present time.

3. THE ARCHITECTURE OF THE MULTIPROTOCOL CNC SYSTEM AxiOMA Control

Realizing the invariant property in the architecture of the CNC system basic kernel requires using objects independent from the fieldbus interface. The “abstract drive” class does not depend on interface type and serves for creating objects that correspond to the interface of a concrete drive. The interface type of a concrete drive is defined in machine parameters.

The “abstract drive” class (see Fig. 2) provides realization of the drives acquisition module interface. This is the basic class in CNC system modules responsible for communication based on definite industrial protocols. The suggested approach enables new protocols support without any modifications in the CNC system kernel structure.

The general mechanism of cyclic data exchange (see Fig. 3) ensures coordinated device operation in the real time mode. It uses either cyclic inquiry (polling) or interrupt processing.

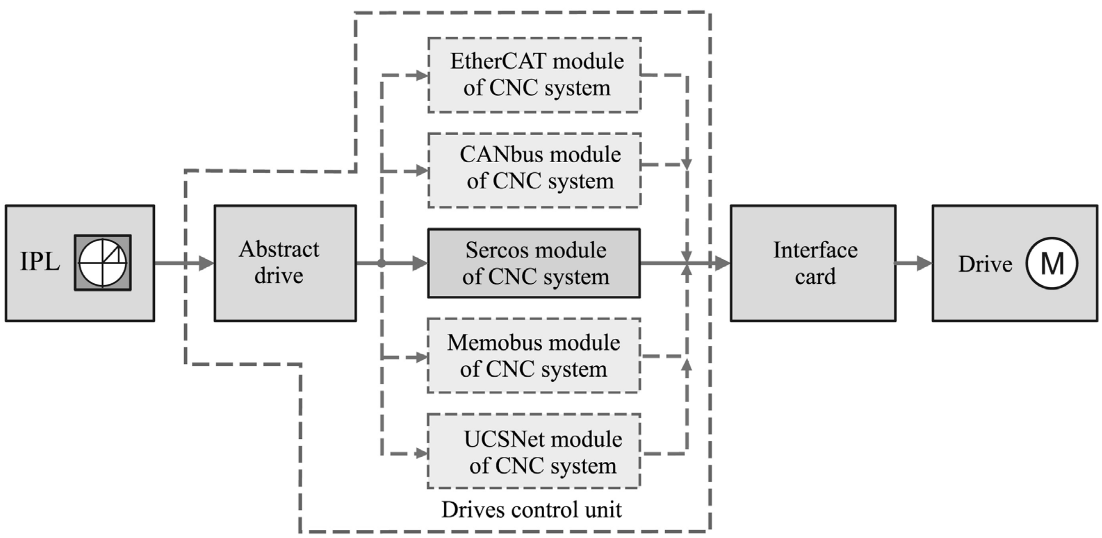

Fig. 2. The architecture of a multiprotocol CNC system.

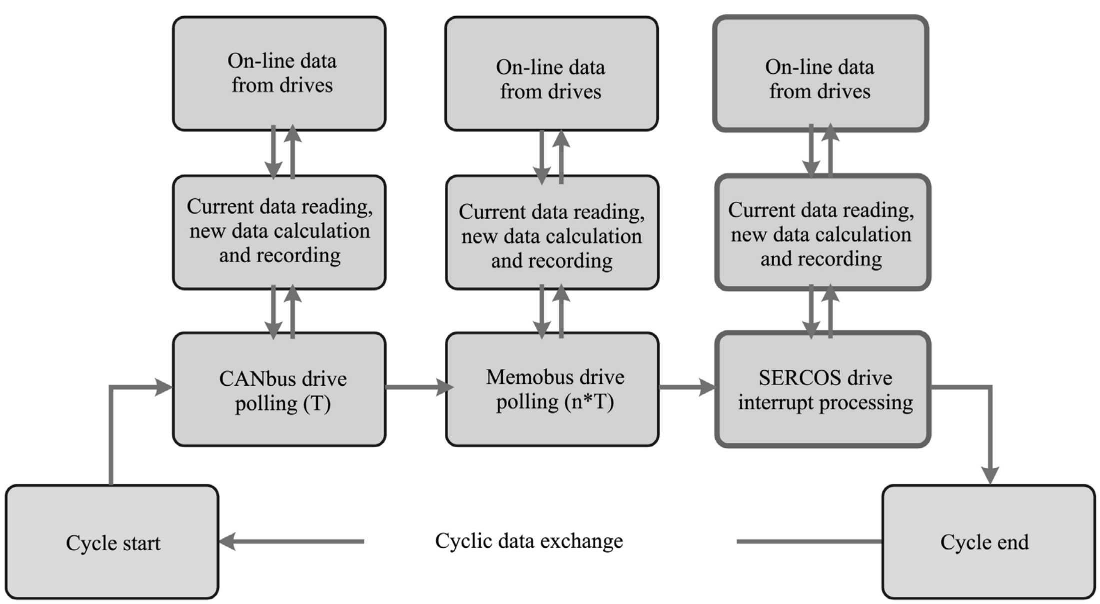

Fig. 3. The scheme of cyclic data exchange.

4. THE PRACTICAL ASPECTS OF MULTIPROTOCOL CNC SYSTEM USAGE

The application of the Memobus and UCSNet protocols is illustrated by the example of the turning lathe *SA-700* with the CNC system *AxiOMA Control* [9]. The primary motion drive of the machine includes the frequency converter *Omron F7 Varispeed* with the feasibility of Memobus protocol control. The machine axis drives incorporate the domestic servoamplifiers *Robokon SD-5* operating via the UCSNet protocol.

Machine control is realized by the bicomputer modification of the CNC system which includes the terminal part based on Windows XP and the real-time machine supervised by Linux RT. The multiport PCI board *MOXA* implements communication of the CNC system with the converter *Omron F7* and the servodrives *SD-5*. The mathematical support of the CNC system comprises the primary motion drive control modules on the Memobus protocol and the axis drives on the UCSNet protocol (see Fig. 4).

We consider the practical usage of the CANBus protocol by the example of the portal milling-and-engraving machine *KSMP-500* supplied by Mechatronic Product Factory (ZAO ZMI) with the CNC system *AxiOMA Control* (see Fig. 5) [10]. This modification includes the domestic integrated servodrives *SPSH-10* (supplied by ZAO Servotekhnika). The spindle *ELTE TMPE-3* serves for primary motion realization, being controlled by the frequency converter *Control Techniques Unidrive SP*. Communication between the primary motion drives and the axis drives is performed via the CANbus protocol using the CANbus PCI board *MARAFON* supplied by a Russian manufacturer.

Realization of the SERCOS protocol is demonstrated by the example of controlling the high-precision coordinate table *Bosch Rexroth* with external measuring scales, *IndraDrive* drives and remote inputs/outputs under the supervision of the CNC system *AxiOMA Control* (Fig. 6) [11]. The solution incorporated in the CNC system kernel supports both interface versions. At the initial stage, a master device (the SERCANS PCI board) is searched. At the next stage, the type of the SERCOS interface is determined (SERCOS II, SERCOS III or another future interface from this family). The functions of initialization, configuration and formation of control commands are carried out depending on the type of interface. Each interface has specific commands, but they may have unified form.

Communication between the CNC system and the drives controllers is realized by the SERCANS PCI board through a programmable driver which organizes the interface of access to the internal memory slot of the SERCOS master device. This driver is used for the real-time transmission of

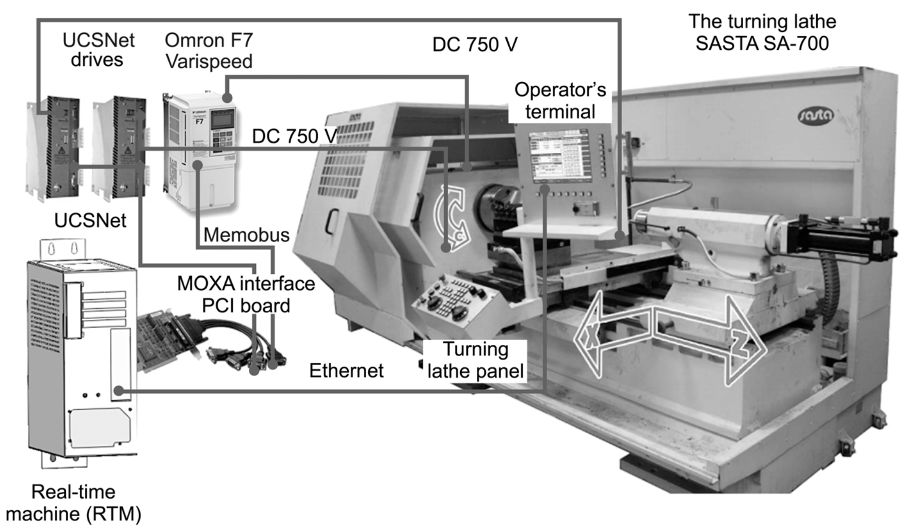

Fig. 4. The turning lathe *SASTA SA-700*.

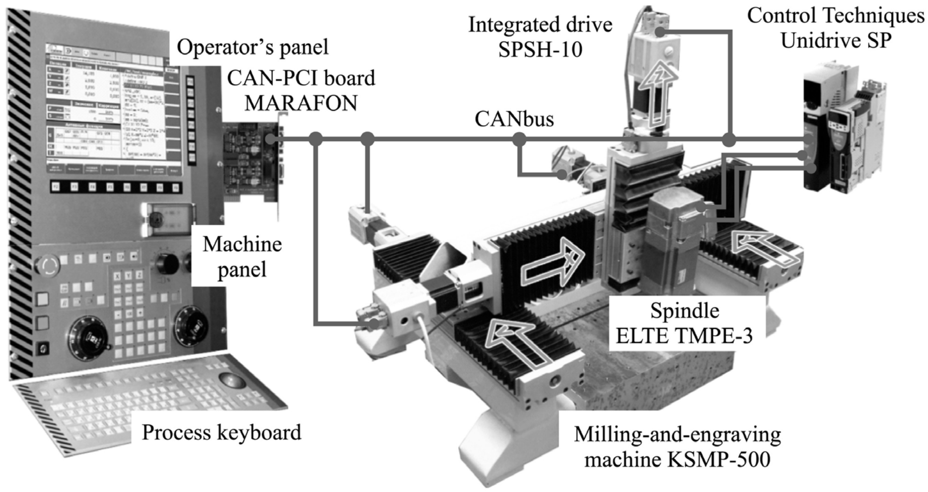

Fig. 5. The milling-and-engraving machine under the supervision of the CNC system *AxiOMA Control*.

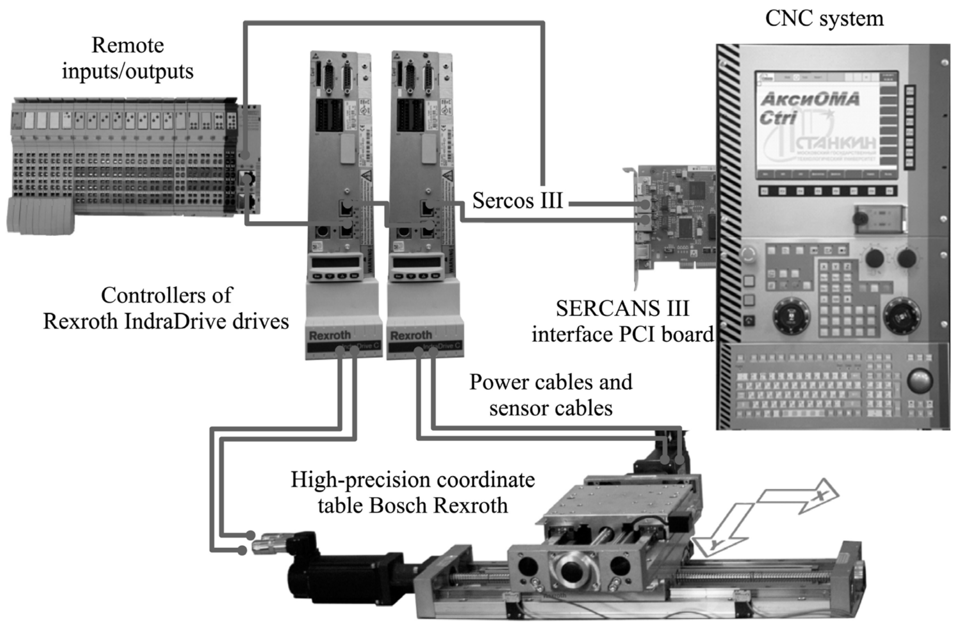

Fig. 6. The high-precision coordinate table *Bosch-Rexroth* under the supervision of the CNC system *AxiOMA Control*.

the cyclic data and current parameter values, the asynchronous processing of the drives parameters or the SERCANS board parameters, as well as for the receipt of diagnostic messages from all nodes of the SERCOS-network.

The main function of the driver lies in interrupt service routine (ISR). The routine checks the cause of each incoming interrupt. In the case of drives data arrival (the so-called answer telegram), the functions of cyclic data reading and recording are activated serially.

5. CONCLUSION

The suggested design method of a multiprotocol CNC system for technological equipment allows its arranging for different process tasks with standardized data exchange protocols for real-time control of actuating devices and input/output modules. The CNC system architecture remains fixed, modifications affect only the hardware level and communications environment. Such approach reduces the adaptation time of the CNC system to machines constructed from different-supplier modules and appreciably enlarges its application domain.

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