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ScienceDirect
Procedia CIRP 46 (2016) 525 – 528
www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

An ARM-based Multi-channel CNC Solution for Multi-tasking Turning and Milling Machines

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Abstract

ARM-based CNC systems are used as a low-cost solution for controlling 2-3 axis machines. The increase of computing power of ARM processors facilitated their application to controlling multi-tasking and multi-axis machines with several independent control channels. The paper presents the results of the exploratory investigation of the transition from the PC-based to the ARM-based CNC solution. The cross-platform architecture of CNC systems, the porting of CNC kernel software to the single-board computers Raspberry Pi 2 with the Linux operating system and the control of servo drives and PLC I/O over EtherCAT fieldbus with cycle time of 2 ms are investigated as well.
The dual-channel configuration of ARM-based CNC designed to control the multi-tasking turning and milling machine with inclined layout is presented. The paper illustrates the kinematic scheme and the network architecture of NAKLON 535 machining center for ARM-based CNC solution.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz

Keywords: computer numerical control (CNC); machine; performance; ARM processor; EtherCAT;

1. Introduction

ARM (Advanced RISC Machine) processors are used today to create stand-alone PLC controllers or specialized control panels and remote control panels for manual handling in the work area that are connected to the CNC system as terminal clients [1, 2]. A number of recently published research papers in the area of embedded CNC devices are of particular interest. Such systems are used as low-cost two-dimensional CNC for laser or waterjet cutting [3] and other uncomplicated machine tool [4] and robotic control [5] systems.

Unfortunately, a serious research on the applicability of the embedded CNC devices for controlling multi-channel and multi axis machine tools is still to be developed. The analysis of single board computers based on ARM-processors shows a steady increase in computing power by increasing the processor speed, the number of cores and memory space [6].

The trend towards increasing the computing power of ARM processors facilitated their application to controlling multi-tasking and multi-axis machines with several independent control channels (Table 1).

Table 1. Single-board computers based on ARM processors with Linux operating system, which were used for running the NC kernel.

Name	CPU	RAM	Ethernet	Price
Cubieboard 3 (cubietruck)	ARM Cortex-A7 dual-core 1 GHz	2GB DDR3	1xRJ45 1G Ethernet	$89
Raspberry Pi 2	ARM v7 quad-core Cortex-A7 900 MHz	1GB SDRAM	1x RJ45 10/100	$35
Cubieboard 4 (CC-A80)	A80, ARM big.LITTLE octa-core (quad-core Cortex-A15 2.0 GHz, quad-core Cortex-A7 1.3 GHz)	2GB DDR3	1xRJ45 1G Ethernet	$125

An ARM based CNC system should implement the modern control technologies for high performance cutting, e.g. spline

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
doi:10.1016/j.procir.2016.04.036

interpolation (Akima spline, cubic spline, NURBS), look-ahead > 150 blocks, clamping corrections, 5-axis transformation, tool correction, path smoothing functions, safe operation of the machine, etc.

The paper presents the results of the exploratory investigation of the transition from the PC-based to the ARM-based CNC solution in particular for the machining center NAKLON 535.

2. Technical requirements and the existing CNC solution for machining center NAKLON 535 with inclined layout

The effectiveness of turning and milling centers is achieved by equipping them with high-speed milling spindles, which allows machine parts with complex geometry in a single setting. This not only increases accuracy, but also reduces the amount of required equipment and time necessary to perform the auxiliary transitions, including the reduction of the number of part setups, and the preparation time of technological equipment and cutting tools, which ultimately increases the utilization rate of equipment and releases the production area [7].

The kinematic scheme of the machine tool requires two-channel control (Fig. 1). The first control channel includes the turret 2 (axis Z2, X2), and the spindle unit S1. The second control channel is assigned to the turret 1 (axis X1, Z1), the longitudinal axis Z and the spindle unit S2.

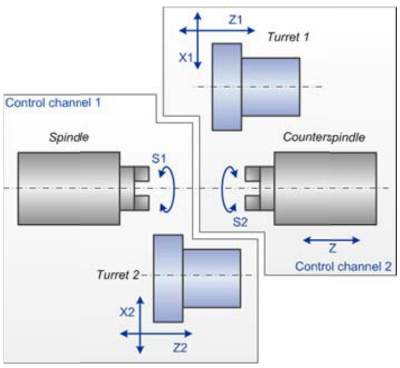

Fig. 1. The kinematic scheme of NAKLON 535 machining center.

Table 2. The high-level language constructs for synchronization between control channels.

Function	Description
channel_load()	Loading a part program on a control channel without running
channel_run()	Loading and running a part program on a control channel
channel_start()	Starting/continuing a part program on a control channel
channel_stop()	Stopping a part program on a control channel
channel_reset()	Resetting the control channel
channel_wait()	Waiting for the end of the part program on a control channel
sleep()	Suspending the running of a part program for the specified number of milliseconds

The working mode of multiple control channels is set in the NC machine parameters, where the number of available control channels is defined and axes for each particular channel are fixed.

The synchronization between control channels is carried out with the help of high-level language constructs (Table 2), implemented by the NC kernel.

The NAKLON 535 machining center with a limited set of auxiliary equipment, including a mechanism for hydraulic chuck clamping system, lock/unlock turrets, etc. was demonstrated at the exhibition “Metaloobrabotka 2015”.

The network architecture of the CNC system (Fig. 2) includes: the NC kernel based on an industrial PC with operating system RT Linux and NC terminal integrated into a Soft PLC (consisting of the operator panel on the .NET platform, a standard and a specialized machine control panels); buscouplers and expansion I/O for PLC controlled devices; controllers of servo drives, spindle and counterspindle [8]. Control and exchange of data in real-time network devices is performed via the EtherCAT protocol. A large number of PLC-controlled devices connected to the NC system required the use of several bus couplers that allowed for the proportional distribution of the electrical load among separate devices.

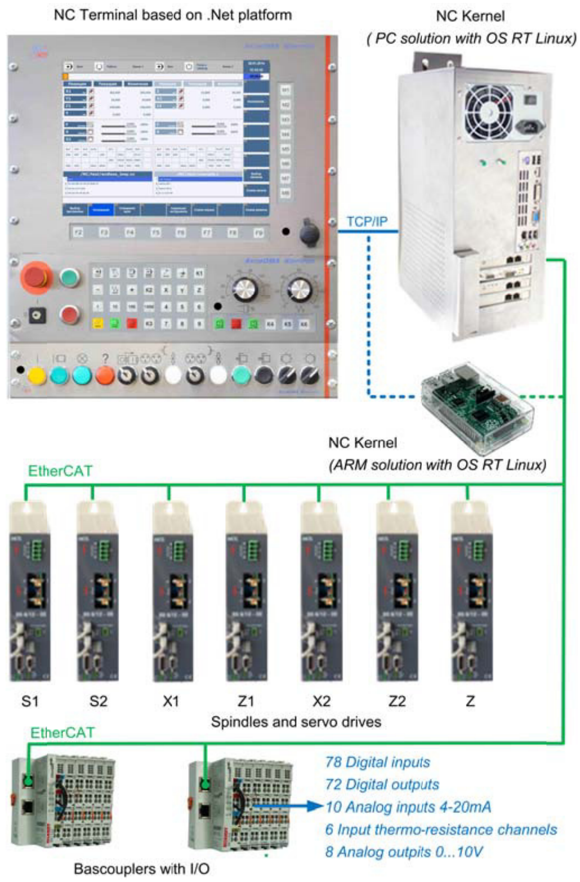

Fig. 2. CNC network architecture of NAKLON 535 machining center.

Structurally, the transition from PC-based solutions to the ARM-based solution is shown in dashed lines and is reduced to switching EtherCAT and Ethernet cable from the PC to the Raspberry Pi 2.

3. Research of the cross-platform architecture and the portability of NC kernel on a single board ARM computer

The portability of the NC kernel software is conceived in the model of the control system created as a type of virtual machine, which has a strict hierarchy of the layers [9,10]. NC kernel models of virtual machines for PC-based and ARM-based solutions are built (Fig. 3). The restriction is handling the EtherCAT protocol with a software master [11].

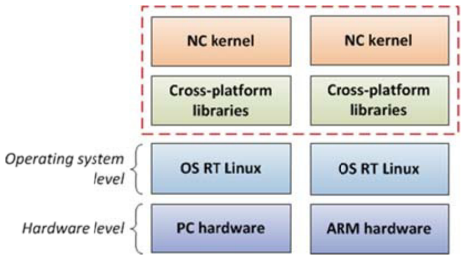

Fig. 3. NC kernel models of virtual machines for PC-based and ARM- based solutions.

The hardware is on the lower level. The PC solution uses the motherboard GIGABYTE GA-Z77M-D3H with an Intel Core i3-3250 3.5 GHz processor, 4 Gb memory and an additional network card PCI-E D-link DGE-560T/B1A to control servo drives and auxiliary devices via EtherCAT protocol. The interpolation and PLC cycle is 2 ms. The communication with the operator terminal is performed via the built-in motherboard network output.

ARM solution uses Raspberry Pi 2 (Table 1). The network output on the board is used to control the servo drives and auxiliary devices via EtherCAT, while the connection to the terminal is carried out via an adapter USB/RJ45.

At the level of the operating system, PC and ARM solutions use the RT Linux operating system, which provides the same API (application programming interface) functions, but has a different hardware abstraction layer for each of the hardware platforms.

Platform independent libraries are identical for both solutions, since the same operating system API interfaces are used. The use of platform-independent libraries in the architecture ensures the portability of the NC kernel on different platforms.

The NC kernel is identical for both solutions, which ensures the simple transfer of NAKLON 535 NC machining center settings, including the machine and kinematics parameters. The dashed red line marks the identical software modules that have been recompiled under a particular platform.

The computational capabilities of ARM solution are inferior to the PC solutions, but this is compensated by the limitations in the CNC system machine parameters on the use of up to 2 control channels, no more than 8 interpolated axes (including 2 spindles), as well as restrictions on the size and the number of elements of the PLC program.

4. Conducting the tests

Bench tests have been performed using the configuration parameters of the real machine tool and its PLC program.

The stand is equipped with 6 servo drives and buscouplers from different manufacturers connected via EtherCAT interface (Fig. 4).

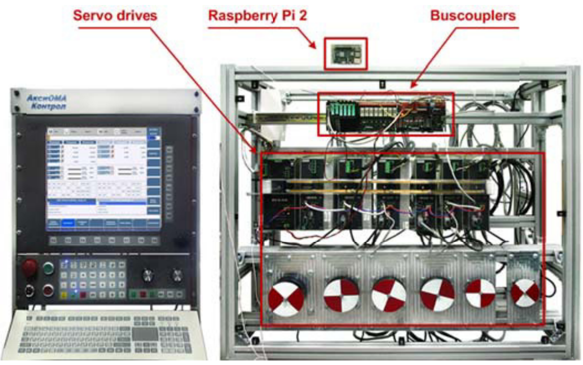

Fig. 4. Test equipment with ARM based NC kernel.

The axis Z is not directly involved in the process of interpolation and performs auxiliary functions to intercept the part from spindle to counterspindle, so for testing it has been configured as an axis with a virtual drive.

The standard operator panel and machine control panel are used as the terminal part. The parameters such as MTBF (mean time between failures) > 2000 h, EtherCAT cycle time (2 ms), PLC program cycle time, correct work (2 ms), etc. have been verified.

The fig. 5 illustrates the CNC kernel drive system performance tests without starting any PLC program. CNC kernel needs about 20% CPU resources for itself before running a part program.

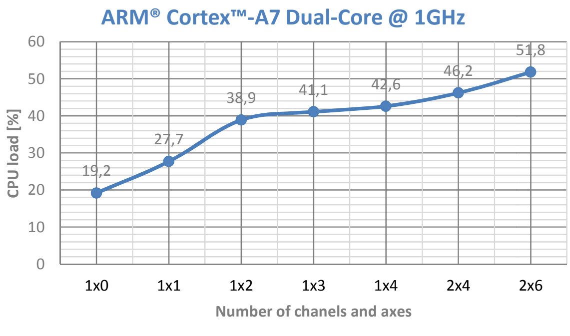

Fig. 5. Results of CNC kernel drive system performance testing without PLC program.

The results of testing CNC kernel with 6 interpolated axes and PLC programs containing up to 20 000 elements in the FBD language are illustrated on fig. 6.

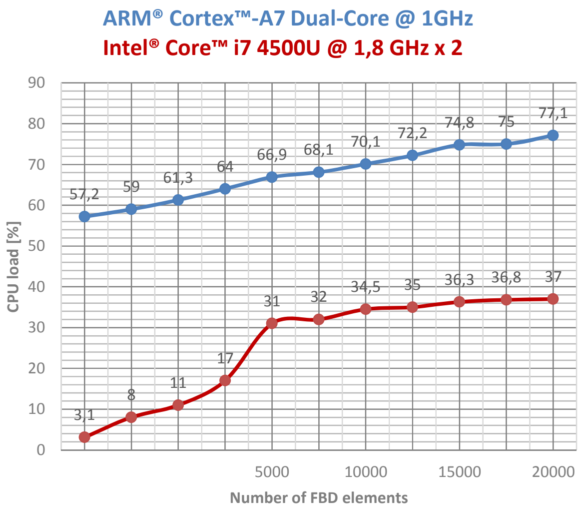

Fig. 6. Results of testing CNC kernel with 6 interpolated axes and PLC programs containing up to 20 000 elements in the FBD language.

Further tests have been carried out on the machining center NAKLON 535, a variant without linear encoders. The EtherCAT cycle is 2 ms, which corresponds to the accuracy requirements of this machine modification.

The axes have been calibrated with the help of a laser interferometer Renishaw LX-80 - class 2 as defined in (IEC) EN60825-1. The position errors for both directions movements have been automatically inserted in the table of axes compensation. After calibrating all axes, the positioning error is reduced to the range of 2 microns [12].

Conclusion

The computing resources of the single board ARM computers present on the market are sufficient for performing the key functions of multi-channel and multi-axis machine tools. The announced release of new ARM processors next year creates new prospects for the NC system, such as EtherCAT cycle time reduction up to 1 ms, increasing the number of control channels up to 4 and simultaneously interpolated axes up to 12 [13,14].

Properly constructed architectural decision of NC software kernel allows porting it on a PC platform as well as on an ARM platform [15,16]. The transition from one solution to another one is reduced to carrying machine tool settings from one NC system to another one.

The prototype of ARM based CNC has been demonstrated in a relevant environment correspondent to TLS 6 (Technology Readiness Level). Further development of research involves testing the dynamics of the machine, additional research in the area of precision machining, adaptive control, diagnostic and forecasting of cutting tool wear [17,18], etc.

Acknowledgements

This research was supported by the Ministry of Education and Science of the Russian Federation as a public program in the sphere of scientific activity and Russian Federal Program of Supporting Leading Scientific Schools (grant NSh-3890.2014.9).

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