Synthesis of the 3D Linux-Based CNC System for Precision Machines

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Abstract
This paper proposes a design methodology for a Linux based CNC control system with open architecture capabilities. The developed Linux-based CNC system consists of several software modules such as NCK, PLC, and MMI modules as well as I/O devices. These modules and basic I/O devices are integrated on a single processor platform. In order to verify the performance of the developed system, linear and circular motion errors are measured according to operating conditions in a precision x-y positioning system. In addition, the developed CNC system is applied to a horizontal arm-type CMM with a jerk-limited linear interpolator.

Keywords: Contour Error, Jerk-limited Linear Interpolator, Linux system, NCK, Open-Architecture Controller, PC based CNC, Real-Time Kernel

1. Introduction
Most CNC systems have been developed as a closed architecture and supported by the proprietary technology. Owing to the lack of openness in controllers used today, developers are commonly confronted with closed and proprietary CNC functions. It is virtually impossible to incorporate different types of controllers and sensor-based control schemes [1,2]. Therefore, a Linux based CNC control system with open architecture capabilities is studied to reduce the limitations in this paper.

The Linux based CNC kernel consists of several software modules on a single processor platform so that particular kernel modules can be easily added to and/or removed from the Linux kernel dynamically. The developed CNC system can be integrated with several other functions so as to realize an intelligent CNC system.

Two control schemes are used in the developed Linux-based CNC system. The first control scheme is a cross-coupling control (CCC) scheme to reduce contour error in two-dimensional motion [3]. The second one is a linear interpolator which employs jerk-limited acceleration profiles for preventing structural vibrations and increasing positioning accuracy in a horizontal arm type coordinate measuring machine [4].

2. Architectures of Linux-based CNC system
A Linux-based CNC system based on the software PC-NC [1] is designed to utilize the PC hardware as shown in Fig. 1. Many advantages of PC systems can be incorporated in the developed system. The real-time task is executed in modules potted in the real-time Linux kernel. Many tasks performing various control functions are constructed for the Linux-based CNC system.

3. Design of CNC module
Since Linux and RT-Linux operating systems have open source codes, small-occupied memory size of the real-time kernels, stability and low latency characteristics, as well as free availability, a CNC platform is constructed by using them. Real-time tasks may have higher priorities compared to the Linux kernel, and may preempt it in order to meet deadline requirement. A GTK+ language is used to develop MMI modules. Various control modules are written in C-language.

Fig. 1 Architecture of Linux-based CNC system.
A. Real-time modules

In this paper, real-time task is executed in modules potted in the real-time Linux kernel. Real-time modules require correctness not only in computing results but also in time responses. The NCK (Numerical Control Kernel) and PLC modules are programmed in RT-Linux and implemented by the multi-thread technology. These modules can be loaded into the memory dynamically.

The NCK of Linux-based CNC system consists of three major parts: a 3D motion command generation part, a motion control part and a PLC control part as shown in Fig. 2. The 3D motion command generation part consists of task modules such as an interpolator and acceleration/deceleration controllers. Both linear and circular interpolators are developed by using a reference-word method [6]. The motion controller part consists of a fine interpolator, PID and feedforward controllers to follow a desired path, as well as FIFO(first-in-first-out) communication modules. This module operates at 1ms fixed time interval. Each task is designed so as to operate mutually independent of others. Therefore, user can add new control logics through the MMI modules.

B. Nonreal-time modules

Nonreal-time modules consist of MMI and configuration windows programmed by a graphical user interface based on GTK+ [7]. Users are able to select one of the control laws that have already installed in the Linux kernel and add a new control logic through the MMI module. During the machine cycle, the developed system displays various conditions and status of the system on the monitoring panel such as the current position of each axis, current velocity, and so on. Internal variables of the CNC system, such as interpolation period, controller parameters, and control period, etc. could be changed according to the desired specification of users on the configuration window. Fig. 3 shows the MMI of the developed system.

C. Communication modules

Fig. 2 shows the data flow of each task on the Linux-based CNC system. The data created by each task transmits other task with the ring buffers for stabilization. The critical and the non-critical time tasks are communicated through the FIFO channels. For large amount of data, shared memory regions are used for inter-process communication.

D. Hardware components

Basic hardware components used in the developed CNC system are composed of a digital-to-analog converter with 8-differential I/O channels, 8 high-frequency-counter chips, and a 32-bit multi-channel digital I/O board as shown in Fig. 4.

4. Application

In order to verify the performance of the developed system, the Linux-based CNC system has been applied to a precision x-y positioning system and a horizontal arm type coordinate measuring machine. System parameters and controller gains have been...
manipulated appropriately by using the Ziegler-Nichols method in each application case [8].

Fig. 5 Result of circular motion error.
(Radius:25mm, Feedrate:1000,2000mm/m)

Fig. 6 Result of linear motion error.
(Feedrate:1000,3000mm/m)

A. X-Y table
(1) Linear & Circular interpolator tests
Linear and circular motion errors are measured with respect to various operating conditions in the precision x-y positioning system. As shown in Fig. 5 and 6, we confirmed that the developed CNC system provided a good tracking performance in various kinds of motion.

(2) Cross-coupled control (CCC)
A cross-coupled controller is formed in the real-time module to estimate contour error in two-dimensional motion. Since the CCC module is dynamically loaded into the Linux-based CNC system, user can easily select this controller according to the purpose of control on the MMI. Linear motion experiments are conducted with various control parameters as shown in Fig 7.

Fig. 7 Result of linear motion with CCC.
(Feedrate:2000mm/m)

B. A horizontal arm type CMM
A horizontal arm type CMM [9] consists of three orthogonal axes is used to verify the measuring and control performance of the Linux-based CNC as shown in Fig. 8.

Owing to the demand for shorter cycle times for measurement tasks, CMMs are required to be used at high speeds. In such high-speed measuring processes, acceleration torques contain high frequency component, which excites the structural dynamics of the driving mechanism and generates undesirable vibration [4]. To reduce the high frequency torque signals, acceleration command profile produced by a linear interpolator should be smooth. The jerk-limited acceleration profile should be included in this system.

Fig. 8 Horizontal arm type CMM.
4.Conclusion

This paper proposes a design methodology for the Linux-based CNC control system with an open architecture. The Linux-based CNC system is designed using commercially available Linux-based software and several I/O devices such as digital-to-analog converters, counter chips, and a digital I/O board. A GTK+ language is used to develop the MMI modules in the Linux system and various control modules are written in C-language.

The developed Linux-based CNC system is applied to two different motion control systems, which are a precision positioning system and a horizontal arm type coordinate measuring machine.

In order to verify the performance of the developed system, several motion control experiments have been conducted in the application systems with various operating conditions.

References
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