# A Novel Embedded Numerical Control System Based on Resources Sharing

Z.D. Zhou, B.Y. Chen, Q. Liu
School of Mechanical Electronic Engineering, School of Information Engineering,
Wuhan University of Technology, 430070
Wuhan, P.R. China
zudezhou@whut.edu.cn, chenby@whut.edu.cn, qliu@public.hb.wh.cn

***Abstract*—New requirements for current network numerical control (NC) were discussed. The authors put forward a new kind of embedded NC system based on resources sharing. In this system, embedded controllers connected by field buses composed the basic NC unit. These units connected to an embedded NC service system providing abundant functions and higher processing abilities through networks to acquire the integrated function in NC processing. Remote NC operating and monitoring can be achieved by remote control terminals connected to the embedded NC service system. Also the system can connect to the enterprise or global manufacturing networks to become one of the online processing units. Then, the paper introduced both the hardware and software of each module of the system in detail. Both the three-dimensional scrolling display effect of the processing trace and the solid figure display effect of the processing work piece acquired at the remote control terminal were shown at last. The results indicate that the system can perform well in the network numerical manufacturing environment.**

***Keywords*—resources sharing, NC service system, embedded web server, remote control, monitoring, open architecture**

## I. INTRODUCTION

From the systems using discrete components to the systems using special purpose computers, and then to the systems presently using general PC, NC technology has developed to a relatively high level. Various multi-axial NC machines, NC processing centers and even flexible manufacture systems (FMS) have been designed.

The general industrial PC, because of its powerful function, rich resources, convenient development, open structure and graphic man-machine interface, is commonly used as the computer platform by foreign and domestic NC systems. Recently, Software NC systems based on PC have been designed which implement the overwhelming majority of control functions including PLC and servo control in software and connect to driving and executing units through communication buses.

With the rapid development of microprocessors, NC systems based on embedded technology began to garner much more importance. And some researchers have carried out relevant researches as in [1]-[4]. Products based on embedded technology appeared like E*ENC555 by ECKELMANN company in Germany. On the other hand, the demands of interconnection and interoperation have become more and more urgent so that relevant industrial standards like open modular architecture controller (OMAC) in respect of the open NC structure have been proposed and established as in [5]-[8]. In addition, open NC systems have been widely researched and applied such as the research of distributed NC system structure [9]. At the same time, software component technologies such as COM, CORBA and OPC have been applied to open NC systems as in [10], [11].

The combination of manufacture and information technology, especially with the appearance and development of network-based numerical manufacture technology, gives a new requirement and opportunity to NC technology [12]. In the network numerical manufacturing environment, manufacturing equipment will become a resource node of an enterprise or even a global numerical manufacture network, receiving and executing tasks, commands from the numerical manufacture networks and monitoring equipments. Corresponding to that, the new demands of network-based numerical manufacturing are not merely network connection of NC systems. The numerical manufacturing systems need to allot diversified processing tasks to relevant NC machines according to processing demands submitted by clients. In order to satisfy various and dynamic changing processing needs, it is necessary for the NC system to dynamically change or add functions without changing its hardware configuration. And this is the essential ability of the service-oriented NC systems in the network numerical manufacturing environment.

But current NC systems, whether based on the combination of hardware and software or totally based on software, are mainly single-machine system structure. That means the system takes a computer as the main controller, and other assistant controllers as supplements to integrate majority of NC functions in it. One of the significant problems existing in this single-machine structure is the lack of flexibility. For example, system software can hardly be changed dynamically to meet the actual demands of production, especially for those complex and large-scale systems because of the close coupling of their software and hardware. If the functions changed, the whole system may be replaced often. This is neither convenient nor economical for users. The other problem is the waste of NC resources. Generally, large, multi-function and high-precision

NC software system is very expensive. However, according to the single-machine structure, NC machines with the same or similar functions have to be equipped with duplicated software. Actually, it is unnecessary to do so because different NC machines can share most or even the whole NC software through networks. The production capacity of those small enterprises or plants can also be improved by remote resources sharing even if they just own a few simple NC machines.

In order to overcome those shortages of current NC technology such as the lack of flexibility in functions and structures, the coexistence of excess and deficiency in resources and the complexity in system architecture, this paper proposed an new embedded NC system based on resources sharing. The architecture of the system is simple and flexible so it is easy to accomplish interconnection and interoperation. Furthermore, it is convenient to expand and reduce functions in the light of real processing demands, therefore meet the needs of different control object. In addition, it provides convenient remote control and monitoring, and makes the most of the available information and NC resources, in accordance with the development of modularizing, flexible and network-base NC system.

The rest of the paper is organized as follows. Section II proposes the entire integrated system architecture. Section III and Section IV presents the hardware and software structure of each module in detail respectively. Section V presents the implementation of the whole system briefly. Section VI gives the real processing effects of the system applied to a workshop. Section VII concludes the paper.

## II. System Architecture

The basic architecture of the embedded NC system based on resources sharing is shown in fig.1.

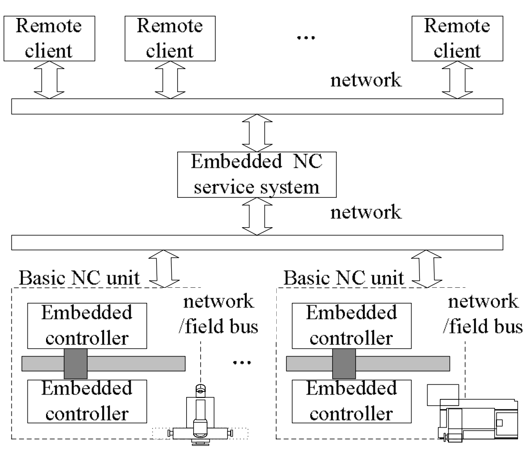


Figure 1. basic architecture of embedded NC system based on resources sharing

The whole system is composed of multiple controllers based on embedded technology interconnected by networks and field buses. There is no fixed mode on how to divide the system into embedded modules, such as which function to be concretely implemented by a module and which implementation technology to be applied. Similarly, there is no fixed mode to adopt a communication technology to accomplish the interconnection of modules. All of these depend on actual needs. Accordingly, to implement interconnection and interoperation, technology standards and communication protocols between different modules can be diversified. So this is an open architecture.

In the embedded NC system based on resources sharing proposed in this paper, each NC machine was equipped with a few necessary embedded controllers with simple single functions such as motion control, servo drive, PLC, etc. Through field buses and networks, these controllers composed the basic NC unit but not the complete system. By connecting to the embedded NC service system (NCSS) providing stronger processing ability through networks, these basic units can obtain the complete NC functions. Operations to machines can be done by remote NC client with NC special client software or general browser connected to the NCSS. The concrete architecture of the system is shown in fig.2.

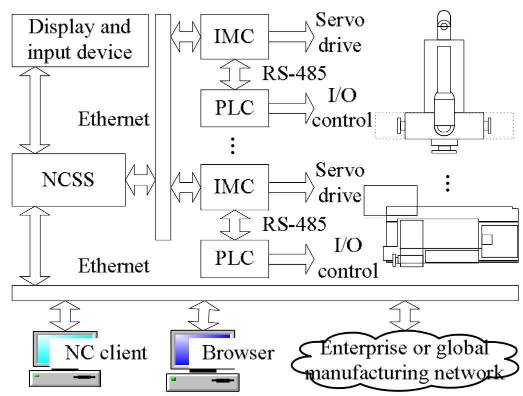


Figure 2. concrete architecture of this embedded NC system based on resources sharing

The whole system mainly comprises the following control modules implemented by embedded technology.

- NCSS: Firstly, it realizes the live man-machine interaction, connecting the display and input device. Secondly, it accomplishes the acquisition, editing and compiling of the processing code. Thirdly, by connecting to external networks, it accomplishes the network-based development, debugging, operation, monitoring and diagnosis of the whole NC system. NCSS is oriented to the multi-machine service which means a NCSS is responsible for multiple machines.
- Display and input device: It accomplishes the command input and the processing state display. 256-color LCD is controlled directly by the display function integrated on the chip. Also keyboard input circuit was expanded through the general I/O ports provided by the chip.
- Interpolation and motion controller (IMC): It accomplishes interpolation, cutter compensation and clearance compensation. Also, it sends position/speed control commands to the servo controller. The IMC connects to the embedded PLC through an EIA-RS-485 industrial bus.

- Embedded PLC: It accomplishes various kinds of logical control and general functions of PLC.
- Position/speed servo controller: It controls the position and speed of the processing axes.
- NC client: It is used as the special control terminal software for remote control and monitoring.
- Embedded web server (EWS): Besides the NC client, remote control and monitoring can be accomplished by the web browser as the general control terminal.

## III. HARDWARE UNIT OF THE SYSTEM

### A. *Hardware of NCSS*

The basic hardware structure of NCSS is shown in fig.3. A S3C2410X microprocessor was adopted. It is a 16/32 bit RISC microprocessor produced by Samsung Company. The chip was developed using an ARM920T core, 0.18μm CMOS standard cell, and the maximum frequency can be 200MHz. It has the advantages of low power consumption, high quality and a high performance price ratio. The external 32M bytes SDRAM and 16M bytes $E^2$PROM were expanded. Two UART of the ARM chip were expanded as two EIA RS-485 bus interfaces whose transmitting rate can be 115kb/s or even higher. One can connect to the IMC module, while the other can connect to the PLC module if necessary. A USB interface was expanded for other uses like development and debugging. An Ethernet interface base on RTL8019AS was expanded on this chip as well to implement the connection to the Ethernet.

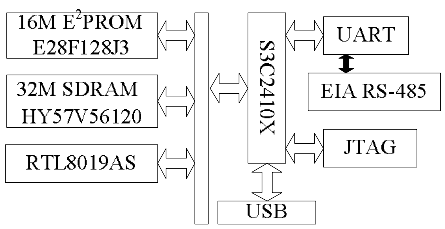


Figure 3. hardware structure of NCSS

### B. *Hardware of IMC*

A 32bit high quality DSP TMS320C2812 produced by TEXAS instrument (TI) was adopted. The chip was developed using high-performance static CMOS technology with 150MHz frequency and the on-chip memory includes 36K bytes of RAM and 256K bytes of $E^2$PROM. Two SCI were expanded as two RS-485 bus interfaces. One was connected to PLC module and the other can connect to NCSS. There are four general timers on this chip which can generate four PWM position feed pulses for the four processing axes. The PWM pulse generated by the general timer as the feed rate assisted with an I/O signal as the direction control was applied as the feed signal for a processing axis. In addition, the CAN2.0 bus interface can be used to convey position control commands or obtain servo control states by connecting to the servo control module. An Ethernet interface was expanded on the IMC also.

### C. *Hardware of embedded PLC*

A C8051F022 microprocessor was adopted in this module. The two serial interfaces of this microprocessor were expanded as two RS-485 bus interfaces. One was used for the connection to IMC and the other can be used for the communication with PLC extended module. 9-way input and 6-way input both applied differential signals to improve the anti-interference capability and the transmission reliability.

## IV. SOFTWARE UNIT OF THE SYSTEM

### A. *Software of NCSS*

The software system comprises two parts: the system environment based on μC/OS-II and lwIP and the application system of multi-machine control service. The software structure is shown in fig.4.

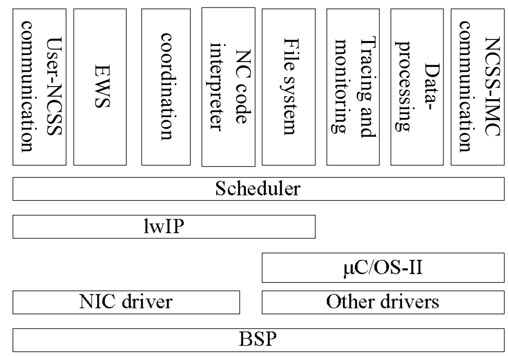


Figure 4. software structure of NCSS

The User-NCSS communication module receives commands or data information from the special remote client. The work also can be done by the interaction between the browser and EWS. When the user's information is received, the checksum is verified to judge whether the data package received is correct or not. If incorrect, the label of the wrong package is sent back to the client that will be asked to resend the relevant package. When the data are received correctly, they are given to the coordination module which will send the semaphore to the relevant processing task according to the identification field read from the package. Then the system turns to the operations of the specified NC machine. The NC code and user's commands are the two types of operations for NC machines. If the former is received, the coordination module sends the NC code pick-up signal to activate the NC code interpreter to finish the extraction and checking of the NC code that will be delivered to the file management module and then waits for the next operation. If the latter is received, for those ordinary control commands, the coordination module sends the semaphore to activate the relevant processing module which calls the NCSS-IMC communication module to finish the transmission of commands. For those NC code executing commands, the file management module picks up the relevant NC code file and the NCSS-IMC communication module is activated to send the NC code in program segment to the specified motion controller in response mode. When the transmission of a control command or program segment finishes, the communication module will open the timer to wait for the confirmation signal of this transmission sent by the motion controller. If the confirmation signal is received in the interval specified by the timer, this transmission will finish or the information will be retransmitted and the time of retransmission will be recorded. If the time exceeds the specified value, the system will exit the relevant processing module and send error messages. During the equipment actions, the state monitoring module sends the equipment feedback to remote clients.

### *B. Software of IMC*

The software structure of IMC is shown in fig.5. Interpolation interrupt service routine (ISR) accomplishes the interpolation, cutter compensation and clearance compensation by calling relevant modules. The feed control module achieves the motion control. First, it accomplishes the transformation from the feed rate to the relevant position control quantity like PWM which will then be sent to the servo control system through a high-speed field bus or PWM and general I/O interface. Four independent feed pulses and position control signals are generated and sent to the servo control system. The PWM control module accomplishes the setting and control of the PWM pulse generator of each motion axis. The main routine receives and processes the NC code and commands and obtains feedback of the processing state by calling relevant modules such as data sending and receiving module, code and commands processing module, logical control module and state monitoring control module. The data sending and receiving module is responsible for the acquisition of the processing code, commands (from NCSS) and I/O state (from the embedded PLC), transmission of I/O logical control commands (to the embedded PLC) and feedback of the processing state (to NCSS). The logical control module transmits I/O control commands (M, S, T code) to the PLC through the RS-485 bus. The state monitoring module acquires the state information of the motion control (theoretical and actual coordinates), I/O control and servo control through the RS-485 bus and the information will be sent to the NCSS.

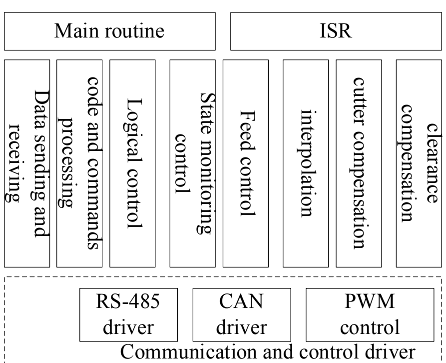


Figure 5. software structure of IMC

### *C. Software of embedded PLC*

The software system of the embedded PLC is composed of the following general modules: a basic I/O control module, communication module, PWM output control module (mainly used for the speed control of the spindle motor) and feedback pulse count processing module of the pulse encoder. The last module is used for counting the feedback pulses of the position/speed servo motor's pulse encoder and the detection of the return-to-zero signals.

### *D. Remote control client*

The main modules and their functions are shown in fig.6. The system is divided into two major modules: the communication module and the man-machine interaction module. The client mainly realizes the following functions.

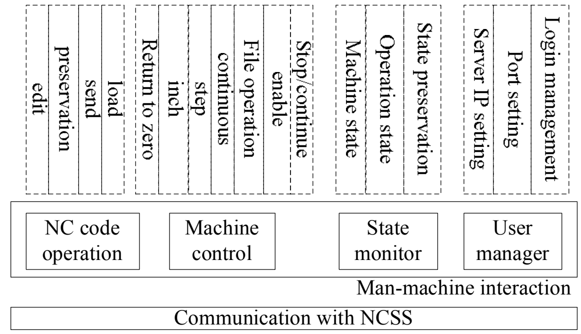


Figure 6. main modules and their functions of remote control client

- User login: Only the authorized operators can be qualified to log into the system and operate.
- Communication
- Man-machine interaction
- Three-dimensional scrolling display of the processing trace: In order to monitor the processing state better, the client provides a scrolling display function about the tracing of recent n segments of the processing curve. Here, n can be assigned according to demands.
- Solid figure display of the processing work piece: The processing work piece is displayed and the display angle can be changed so that the graph can be rotated on both the horizontal and vertical planes. The function mainly used the GigaSoft PoEssential v5.0 graphic database. The three-dimensional graphic interface provided by ProEssentials was applied and real-time processing position vectors were applied as the input array.
- User management: As a remote control system, there are two basic issues which must be solved. The first is that only the authorized users are allowed do the remote operation and control. The second is how to manage the situation of multiple remote clients attempting to control the same machine at the same time. The first problem can be solved by identity authentication and operation authorization. Authorized users are divided into system administrators and operators. System administrators are responsible for creating and deleting users, and setting and modifying passwords but cannot operate machines. Operators can only operate machines but cannot manage users. For the second problem, the system follows the principle that the first access has the highest authority. That means only the first user who connects to the NC system has the operable authority and other users only have the browse authority to avoid the conflict of operations.

*E. Remote control based on EWS*

Compared to special client software, a web browser as the remote control and monitoring client has features of simplicity, convenience, standardization and good expansibility. The purpose of EWS in an NC system is to provide the remote control and monitoring based on web browser. EWS is in NCSS and comprises two parts: embedded web and NC web application service as are shown in fig.7. The embedded web provided the basic web service function, namely, the HTTP request and response. The NC web application service is responsible for the receiving and pretreatment of operation and monitoring requests submitted by the browser. Also it sends relevant requests to the embedded NC system and returned results to browsers. One of the real-time active pages is shown in fig.8.

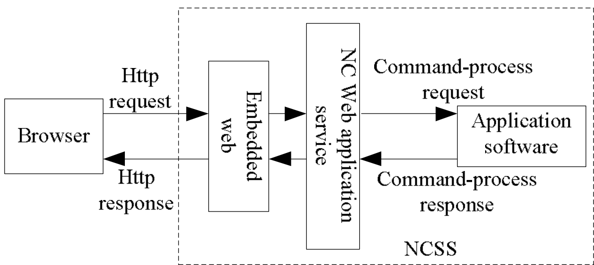


Figure 7. EWS structure

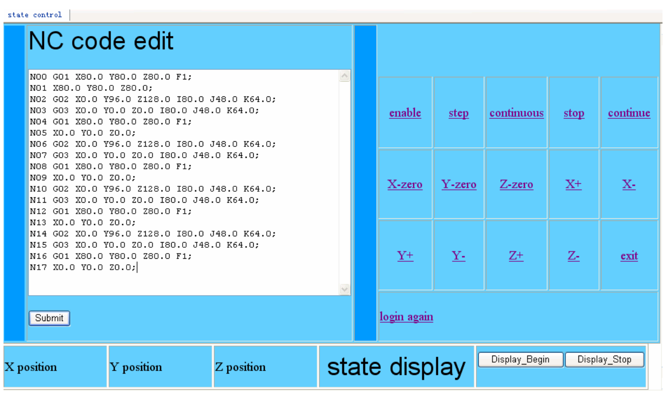


Figure 8. real-time active page

## V. SYSTEM IMPLEMENTATION

The system implementation is shown in fig.9. The work flow is described as follows. The whole system is in a numerical manufacture network.

- Step A: Users prepare data or commands in remote NC clients.
- Step B: Users' prepared commands and data are sent to the NCSS.
- Step C: After interpreting the commands and data received into the format which can be recognized by each motion control module, the NCSS transmits them to the specified NC unit. In addition, the NCSS asks for the current state information from motion control modules in every definite interval.
- Step D: Basic NC units response to the interpreted commands or data and execute relevant operations. To implement monitoring, they send the feedbacks to the NCSS according to the NCSS' command in every definite interval.

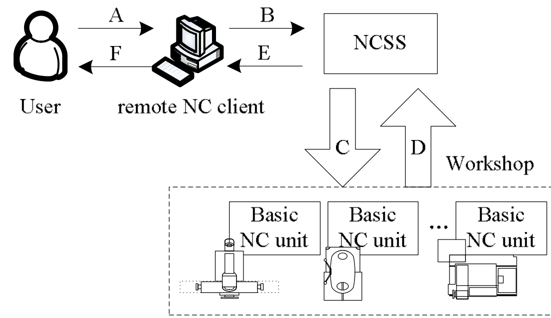


Figure 9. System implementation

- Step E: The NCSS transmits the feedback information received and users' relevant operation information to remote clients.
- Step F: Users can remotely trace the process state and inspect each unit like the PLC, servo control, etc.

## VI. EMPIRICAL STUDIES

The system has been actually used in an NC workshop in which there were some milling machines and punching machines. The following figures are the three-dimensional scrolling display effect of the processing trace (fig.10 and fig.11) and the solid figure display effect of the processing work piece (fig.12 and fig.13) acquired from the remote control terminal during a milling machine's processing.

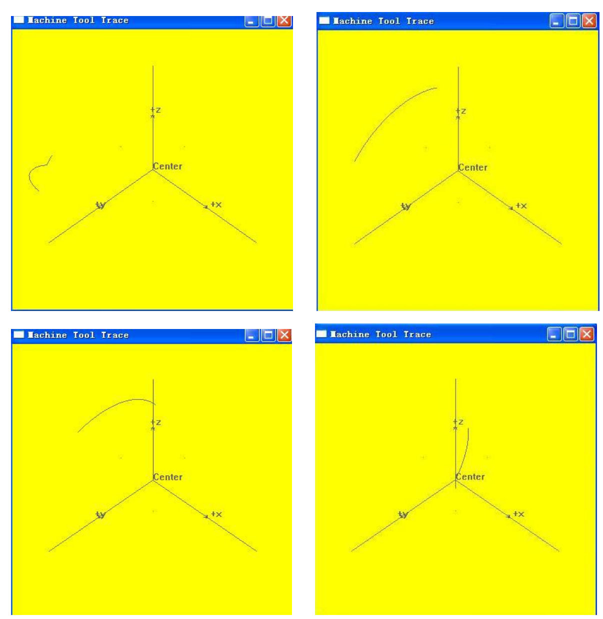


Figure 10. three-dimensional scrolling display effect (subsection)

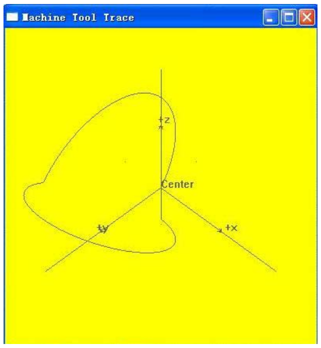


Figure 11. three-dimensional scrolling display effect

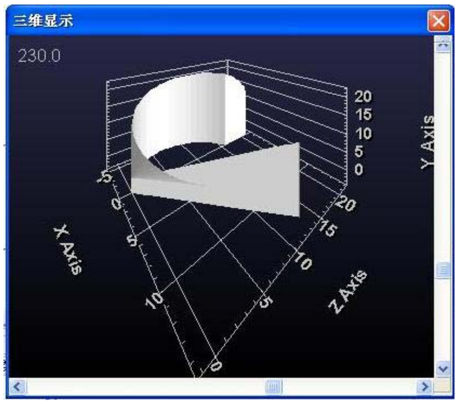


Figure 12. solid figure display effect of the processing work piece (subsection)

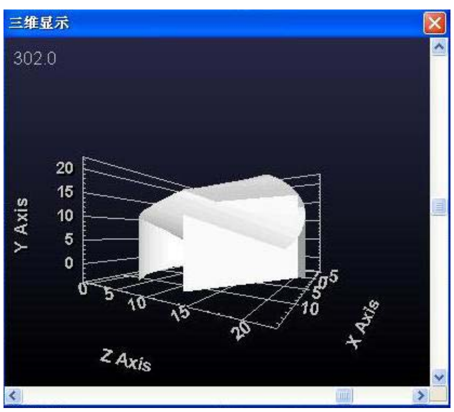


Figure 13. solid figure display effect of the processing work piece

## VII. CONCLUSIONS

In this paper, the authors have proposed the architecture of the embedded NC system based on resources sharing. This architecture is different from the current NC architecture most commonly in use. It is a newly developed NC architecture that fully utilizes the embedded and industrial communication technology. The structure of the system is simple, flexible, and has no fixed form. It is easy to acquire interconnection, interoperation and expansion. Both the software and hardware sub-systems are easy to customize and have high flexibility. The system provides convenient remote control and monitoring in accordance with developing trends of network-based and unmanned processing of plants. Most importantly, the remote control and monitoring technology based on the browser makes the operation easier and more convenient. The embedded NC system based on resources sharing can control multiple machines simultaneously. Each machine only has to install and configure a few of the most basic embedded controllers inserted into the control networks so that required NC functions can be obtained. Also, which NC service system the basic NC units connect can be allocated and changed flexibly. This study shows that the embedded NC technology based on resources sharing is feasible and has its unique advantage. It performs well in the real production.

## ACKNOWLEDGMENTS

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