Design and Application of a Desktop CNC Lathe Control System

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Abstract. With the acceleration of the development process of various industries, the demand for high-end CNC lathes in the manufacturing industry is increasing, and the development of CNC lathes has great potential to create new opportunities while facing challenges. Desktop CNC lathes reduce cost and volume to a certain extent, this paper puts forward the joint dual STM32 and FPGA embedded numerical control system, re-divide the processing mode, design the corresponding hardware and software system, after laboratory verification, the experiment proves that the embedded CNC system can meet the general CNC processing needs.

Keywords: CNC machine tools · Embedded development · STM32 · FPGA

1 Introduction

CNC lathe is the product of the combination of modern electronic information industry and manufacturing industry, taking numerical control technology as the core system and keeping up with the pace of world electrical integration is an important goal of lathe development at present. The world machine tool manufacturing industry has entered the era of mechatronics development with electronic digital manufacturing technology as the core, that is, using digital information control system to support technology development, and CNC lathe is one of the main representative achievements of its technology development.

As far as the social economy itself is concerned, manufacturing industry is an important foundation to support it to carry out a series of activities efficiently, and the production and processing technology and equipment quality involved will have an impact on the national economy to a certain extent. When China's manufacturing industry is aware of the rapid development of foreign manufacturing industry, it should keep up with its pace of development, innovate and reform CNC machine tools, and promote the improvement of the technical level of the whole manufacturing industry in society.

With the continuous enhancement of China's comprehensive development strength, the manufacturing industry has ushered in new opportunities. In recent years, CNC lathes in China have been continuously innovated and widely used in aerospace, shipping and other fields. CNC lathe has become the core equipment of China's modern manufacturing

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industry, with the continuous development of China's economy, the demand for CNC lathe in the domestic market has increased, how to improve the overall quality of machine tools and meet the urgent needs of the future market, so as to boost the economy more effectively, is an important direction of the CNC lathe industry. After realizing the present situation and future trend of domestic CNC lathes, relevant manufacturing units can effectively promote the progress of the machine tool manufacturing industry and help improve the production quality and efficiency of their machine tool products, which is one of the important ways to improve the severe situation that the use of machine tools is in short supply. For the whole society, Exhibition, the national economy can also get substantial progress because of the innovation of modern CNC lathe.

The system completes the work by FPGA and touch screen instead of PLC, and uses STM32F4 to drive the touch screen to complete human-computer interaction, greatly improving the task completion efficiency of CNC lathes, reducing overhead and meeting the needs of automated processing.

2 CNC Lathe Overview

CNC lathe is the abbreviation of digital information control lathe, and it is an automatic machine tool with internal electronic information as the core program control system. Compared with ordinary lathes, this type of machine tool is intelligent and efficient, the central control system can scientifically and orderly handle the operation of specific control instruction codes or other specified operating procedures, and can actually compile them into codes according to the actual operation conditions, thus controlling the machine and machining parts. Under the control of digital information, the machine tool can accurately control the dimensional accuracy and geometric accuracy of parts, and process them into the required shapes. As the machine tool for parts processing, CNC machine tools have a complex system, which is usually composed of digital control system, servo system, quality inspection system and other related auxiliary systems, each system operates in coordination and cooperates in an orderly manner to complete parts processing with good quality and quantity.

3 Hardware System Design for CNC Machine Design of Desktop CNC Lathe Control System Based on Dual STM32 + FPGA

According to the new requirements of desktop CNC lathe for cost and volume, an embedded CNC system based on dual STM32 and FPGA is designed. The machining mode of NC system is subdivided, and the task of NC system is divided into two parts according to the client-server design mode. According to the task requirements of the two parts, the corresponding hardware system is designed, and the specific software functions are researched and realized on the corresponding hardware platform. Finally, turning experiments are carried out on two different desktop lathes, which verify the shortcomings of the modified CNC system in terms of function, precision and stability, experiments show that the embedded CNC system can meet the general needs of CNC machining.

3.1 CNC Lathe Control System Mode Classification

The boundary of traditional NC system mode is fuzzy, which easily confuses beginners. The analysis of the functions and implementation modes of these modes can be summarized into two modes: manual processing and automatic processing.

Reasonable functional classification helps to clarify the task content and lower the threshold of use. In the specific implementation, the two modes have overlapping implementation modes, and some hardware and software can be shared. According to the client-server design pattern (C/S), the control system of CNC lathe is divided into two parts: client and server. Client mainly completes human-computer interaction, and server mainly completes parameter modification, action execution and core functions of CNC system, and G code execution. The two parts mainly realize that the server receives and executes the client instructions and returns the execution results through the self-defined asymmetric communication protocol, so as to cooperatively realize the two processing modes.

3.2 Hardware Design

Hardware is the foundation of numerical control system, and the hardware design should meet the requirements of numerical control system in data processing capability, multi-axis linkage synchronization, storage capability and anti-electromagnetic interference. Due to the limited space, the specific circuit schematic diagram is not expanded here, and only the hardware part of the numerical control system is analyzed and designed from the demand point of view.

The main task of the client part is man-machine interaction, and the screen display and virtual buttons are the main equipment of man-machine interaction. In order to reduce the workload and improve the development efficiency, many embedded designs use serial port screen to realize human-computer interaction [4, 11, 12], but the design is limited and the serial port screen is oriented to general industrial application scenarios, which cannot meet the high real-time requirements such as coordinate display. Therefore, the STM32F429+ touch screen is used to develop the human-computer interaction in the client hardware design. At the same time, make full use of the rich peripherals of STM32, and add USB and SD interfaces for external G code input such as U disk, keyboard and SD card; Use Flash to realize in-board storage of g code; Add 32MB SDRAM to expand STM32F429 memory, and use it as display memory at the same time; Expand the handwheel interface for external electronic handwheel; Ethernet and RS485 interfaces are reserved to increase system openness and function expandability.

Because the server undertakes most tasks in automatic machining, the server hardware needs to meet the requirements of real-time, synchronization and stability of CNC system. The STM32F767, which has a main frequency of up to 216 MHz and supports floating-point operation, is adopted to meet the real-time requirement of numerical control system. EP4CE15F484 is adopted to synchronously send the motion instructions of each axis to the motor driver. Add SDRAM to expand memory and increase the maximum number of G code lines to avoid system crash; Master-slave communication between STM32 and FPGA using FMC; Because FPGA is directly connected with actuators and sensors, optical coupling isolation is added to avoid external signal interference.

Although the tasks of client and server are completed by two MCU, considering the size and installation, the two parts are integrated in the same PCB circuit, sharing necessary modules such as power supply, clock, emergency stop and indicator light. The overall hardware architecture of the NC system is shown in Fig. 1:

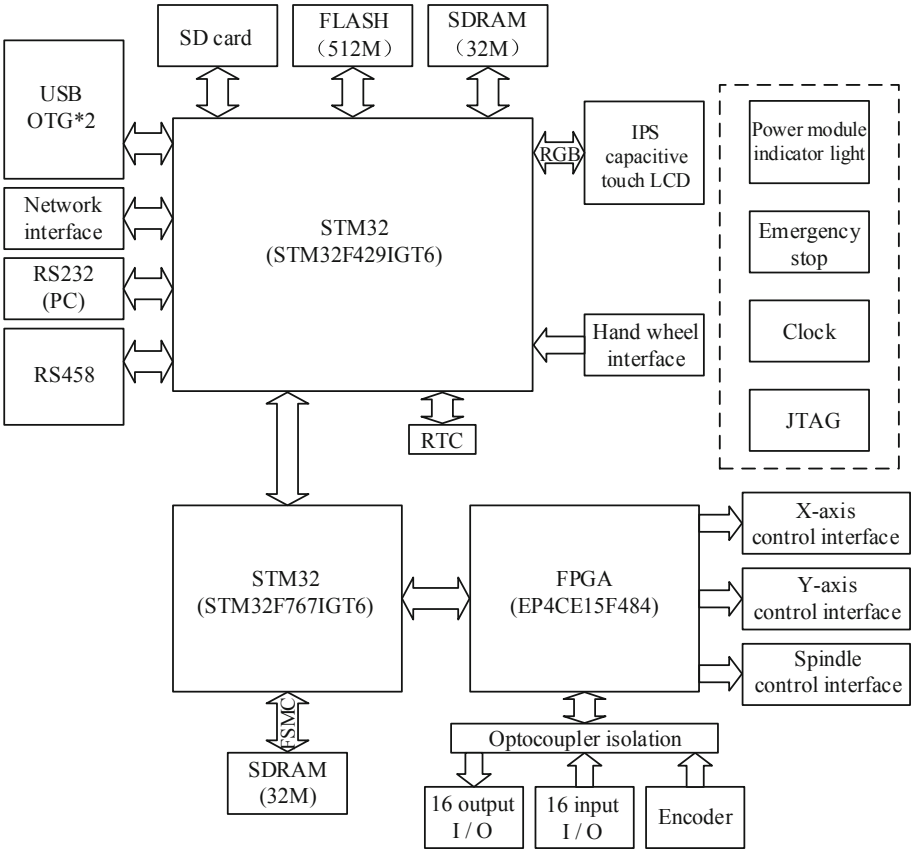

Fig. 1. Embedded CNC system hardware architecture

3.3 Software Design

Software design mainly analyzes and designs client functions and server tasks. Limited to space, and there are many documents [13–16] Decoding, cutter compensation and interpolation are introduced, and all sub-function modules are not described in detail here.

EmWin is a graphic software library developed for embedded platform. The emWin control can be used to complete interface editing like building blocks, and then the LTDC controller of STM32 drives the display screen to realize interface display. EmWin supports touch screen, periodically detects touch interaction, obtains click position coordinates in screen coordinate system, judges whether the control is operated by comparing click position with interface control position, and writes response function in control callback function to realize virtual button function. By coding different button controls, the virtual key input of standard G code or other types of data can be completed by writing the corresponding codes into memory in the button control callback function. Traditional CNC lathes support the use of electronic handwheels, Compared with buttons, electronic handwheels can realize flexible micro-feeding, and control the motor feeding speed according to the shaking speed, which provides great convenience for tool setting and other operations. FatFs is a file system module designed for embedded systems, FatFs can read and write data according to sector information, protect necessary data, and provide generic operation for different storage media. 4 Mbps serial communication is used between client and server to meet the real-time response of big data instructions. There are many types of results returned by the server, and the serial port receives interrupt analysis.

It may cause the client system to have large time jitter, so it is necessary to temporarily store the results with high real-time requirements (such as coordinates) in FIFO buffer, and then analyze the results after other tasks are completed. Touch detection, screen display and result analysis are macroscopically parallel tasks, so the embedded operating system μ C/OS-iii is used for task scheduling, which is the same as the previous one. EmWin and FatFs can also use the semaphore and other shared resource protection mechanisms provided by the operating system for resource protection.

Due to the limited size of server memory, decoding, interpolation and other modules need to be executed in parallel to reduce the demand for buffer, which brings problems of task scheduling and shared resource management. With the development of hardware, the size of on-chip RAM of MCU increases, and RAM can be expanded to increase system memory, so many parallel tasks can be converted to serial execution, thus simplifying design, reducing system coupling and increasing system robustness.

Because the server passively responds to the client's instructions, when the server is idle, it should constantly inquire whether there are instructions delivered through data communication, and call and execute service tasks such as parameter modification, action execution and G code execution through function pointers according to the contents of the instructions. Parameter modification task not only provides necessary parameter modification for automatic machining such as tool setting data, but also can modify motor parameters (maximum speed, acceleration, etc.) and machine tool parameters (maximum stroke, front/rear tool rest, thread pitch, etc.) to improve the flexibility of NC system. The order in which the action instructions are sent will inevitably destroy the synchronization of linkage, so the action execution task only needs to consider the uniaxial action at the same time, that is, the corresponding manual processing mode.

G code tasks include decoding, cutting compensation, speed planning, G code interpretation and other subtasks [16]. Text files read into the system through FatFs are stored in character arrays, if you look for instructions when interpreting g code, you can't meet the real-time requirements of processing speed. Therefore, decoding needs to extract and check the instruction and its data from the character array in advance. Tool length compensation means that when the tool length can't cut the workpiece due to tool change and wear, it can compensate for this missing part without re-setting the tool, saving time; Speed control mainly refers to acceleration and deceleration control, and there is also speed preview control for continuous tiny line segments [17], The trajectories described in G code all start from zero speed and end at zero speed. According to Newton's law, there must be acceleration and deceleration processes, for stepping motors, the machining accuracy is not high under the starting frequency, so acceleration and deceleration can be ignored. Frequent start-stop affects the machining efficiency, and speed preview control introduces switching speed to avoid motor start-stop. G code interpretation converts G code into specific instructions to drive actuator movement. For simple actuators, such as coolant, lighting, etc., only need to control FPGA to generate corresponding high and low levels; For a single complex actuator, such as DC brushless motor, control FPGA to generate corresponding enable, direction level signal and speed pulse signal sequence to send to DC brushless driver; For the linkage of multiple complex actuators, the displacement of each axis is decomposed by point-by-point comparison interpolation, and then the FPGA is controlled to generate corresponding direction level signals and pulse sequences containing displacement speed information, which are sent to the stepper motor driver.

Emergency stop is used for the emergency stop of machine tools in critical situations, if the emergency stop only powers off the main circuit, there is a possibility that the motor will continue to move after the emergency stop is reset, so the emergency stop signal needs to be provided to the numerical control system at the same time to control the motor to stop, for the large inertia part of the spindle, if necessary, reverse the electromagnetic torque properly or increase the mechanical locking device. To sum up, the reference model of the server part is shown in Fig. 2.

This determines the asymmetry of communication protocols. Clients need to call the services provided by the server according to the server protocol, Because of the uncertainty of G code data, if the server receives data in an indefinite way, the time jitter is large, in order to realize fixed-length reception, clients need to send an instruction to tell the server the length of G code first, and then send the corresponding length of G code in the next instruction.

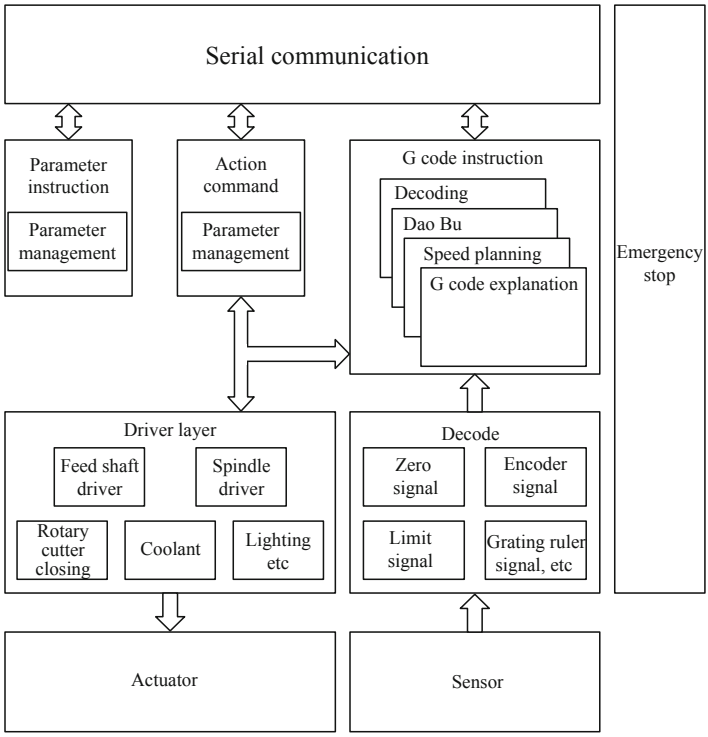

Fig. 2. Server reference model of CNC system

4 Experimental Verification

In order to verify and modify the embedded numerical control system, two machine tools were used respectively, one of which was Nanjing Yima ET 100-ZT NC assembly and adjustment training lathe, and the cutting experiment was completed after selecting the motor and cutting tools; Second, self-designed machine tools. Turning experiments were carried out using the part drawing as shown in Fig. 3.

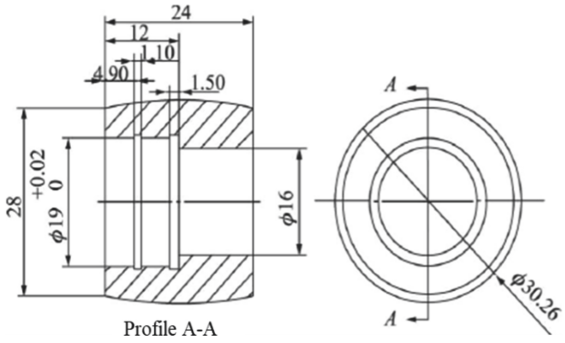

Fig. 3. Drawing of parts to be processed

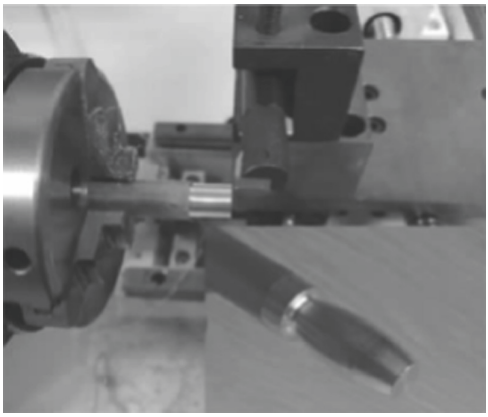

Fig. 4. ET100-ZT machining parts drawing

Fig. 5. Self-designed machine tool machining parts drawing

Table 1. Experimental data for machined part 1

Machine	ET100-ZT	Self-designed machine
Workpiece length	23.985/24	23.991/24
Left end face circle	9.991/10	27.864/28
Right end face circle	9.979/10	29.198/28
Large inner hole	–	18.891/19
Small inner hole	–	16.099/16

Table 2. Experimental data for machined part 2

Machine	ET100-ZT	Self-designed machine
Workpiece length	23.979/24	23.990/24
Left end face circle	9.989/10	27.866/28
Right end face circle	9.981/10	29.199/28
Large inner hole	–	18.892/19
Small inner hole	–	16.098/16

The machining results are shown in Fig. 4 and Fig. 5, and the machining parts data are shown in Tables 1 and 2.

The x-axis stiffness of the self-designed machine tool is poor, which leads to the relatively poor dimensional accuracy of parts in the x-axis direction and the machining surface quality is not as good as ET100-ZT.

5 Conclusion

The traditional CNC system uses PLC to complete most of the input and output signal processing, such as CNC panel compilation, limit signal acquisition and spindle tool change control, etc. This system uses FPGA and touch screen to replace PLC to complete related work, and uses STM32F4 to drive the touch screen to complete human-computer interaction. Use STM32F7 to interpret and execute operator instructions. Reduce the cost of PLC, CNC panel, PC and other parts, and integrate all the hardware in the A4 size PCB board to meet the volume requirements of desktop machine tools. Experiments prove that the embedded CNC system meets the general automated processing requirements and meets the cost and volume requirements of the desktop CNC lathe.

However, due to many choices in the design stage, this CNC system must have many shortcomings: The use of an MCU based on the Cortex-M core sacrifices some human-computer interaction functions, such as trajectory display and simulation processing; at the same time, electronic handwheel pulses are collected on the client side. There must be a problem that the motor execution lags behind the handwheel by one collection cycle, which may bring safety hazards and will be improved in the subsequent design.

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