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Development of Wire Electrical Discharge Machining Control System Based on Cloud Service

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***Abstract* – A cloud service control system is developed to address the intelligence and interoperability of Wire electrical discharge machining(WEDM). The system adopts a modularized structure with cloud server, client and machining terminal. The cloud server mainly executes NC code interpretation, trajectory interpolation and other calculation processes. The client realizes data transmission between the user and the device through the human-computer interaction interface on the server. And the machining terminal is used to control the movement of axis motors and the operation of various auxiliary equipment. This structure transforms the control mode from the traditional synchronous mode to the asynchronous mode. Experiments show that the proposed method is indeed effective in improving adaptability and maneuverability of WEDM. It simplifies the hardware structure and reduces computation load of the processing terminal by using cloud service, which can help to reduce the maintenance cost. The developed method improves the intelligent control of WEDM and compatibility with the goal of Industry 4.0.**

Index Terms - WEDM, system architecture, cloud service, processing terminal

Ⅰ. INTRODUCTION

Wire electrical discharge machining is an electro-thermal machining process for electrically conductive materials. Thanks to WEDM does not involve cutting forces, it is commonly used in cases requiring low residual stresses. Any electrically conductive material can be cut using WEDM, regardless of the hardness, ranging from public metals, including copper, aluminum, tool steel, and brass, to uncommon new alloys such as tungsten carbide, wafer silicon, castalloys, inconel, titanium, carbide, and polycrystalline diamond. Moreover, WEDM can machine high strength, highly corrosive-resistant, highly wear-resistant, and difficult-to-machine materials such as metal matrix composites and cemented carbides. Besides machining electrically conductive materials, some insulating ceramics and nonconductive materials have also been cut with WEDM. With WEDM, it is also possible to machine complicated shapes that cannot otherwise be achieved using conventional machining processes, such as turning, milling, and grinding. Applications of WEDM are also found in fuel injector nozzles, extrusion dies, turbine blades, and aircraft engine. Therefore, WEDM is one of the most commonly known and applied nonconventional machining processes in today’s industrial practice. In this procedure, with the rapid development of computer technology, improvements in WEDM system have rapidly taken place, along the direction of intelligence, networking, integration and high flexibility[1].

Intelligent manufacturing gradually connects machines, devices, sensors and people together. With the core is industrial internet, cloud service is one of the beneficial ways to realize it[2-4]. There have been a wide range of efforts dedicated to investigating on intelligent WEDM and achieved some results. For example, Mori et al proposed remote maintenance and diagnosis of processing equipment[5]. They interconnect the equipment of a company in the world through wireless network. The equipment will send the running status information to the designated mailbox regularly. Through this information, it can predict whether the machine will break down or not, so as to remind the owner of the equipment to take corresponding measures. Coronado et al installed a sensor on micro-EDM machine, uploaded the processing data to the cloud server, on which it could determine whether the discharge process is arc or short circuit status[6]. Zheng et al proposed an encoder-player WEDM system for simplifying the processing terminal and improving the real-time performance of motion control. The system adopted client/server (C/S) mode to separate the interpolation process and the machine motion control. Trajectory interpolation process was calculated in the cloud server and generated motion bitstream file. The numerical control terminal downloaded the file from the server and directly played it to realize machine tool movement[7]. Correa et al proposed a CNC system with Arduino to simply processing equipment, and realized motion control of the three-axis CNC system[8]. While the theoretical foundations and experimental verification were implemented, there is a lack of systematic synthesis. In terms of improving system architecture, it is helpful to optimize the control and management system and the real-time performance of the machine tools[9-11]. On the other hand, with the application of cloud server, data calculation and analysis processes are transferred to the cloud instead of the processing terminal, so the processing terminal only needs to complete the motion control of the machine tool[12]. When we combine these technologies, it is very beneficial to the development of WEDM control system[13-15].

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In this paper, through integrating these technologies and applying on WEDM machine tool, a novel WEDM control system is designed. It includes two main parts: cloud server and processing terminal. Interpolation and artificial intelligence algorithms are executed on cloud server, and processing terminal completes motion control and sensor data upload. Users can control the machine tool by visiting the built website on the server. According to these, process controllers are able to optimize the manufacturing approach and make full use of processing data, including gap voltage, cutting speed and so on, and to react flexibly towards changing processing environment. With the help of the simplification of hardware, the system can be used in more environment, and increased the level of intelligence of the control system.

For this, the remainder of this paper is organized as following. The second part introduces the architecture of the cloud-based WEDM control system. The specific implementation of system functions is introduced in the third part, including cloud server, client and processing terminal. In the fourth part, the validation experiments are designed to verify the feasibility of the system. At last, the conclusion and future research priorities of the paper are summarized in the fifth part.

Ⅱ. ARCHITECTURE OF THE CLOUD-BASED CNC SYSTEM

The WEDM control system is divided into three parts: cloud server, client and processing terminal. As shown in Fig.1. All computational tasks are accomplished on the cloud server, including interpolation algorithms, machine tool fault diagnosis, and processing parameter optimization algorithms. The processing terminal interprets the data sent by the server, based on that, machine tool could finish the motion of each axis, and during the processing cycle, the processing terminal uploads the related information of the machine tool to the server. As for the client, it has a small amount of tasks. The main tasks are to send interface requests to the server and upload operations of the user to the server.

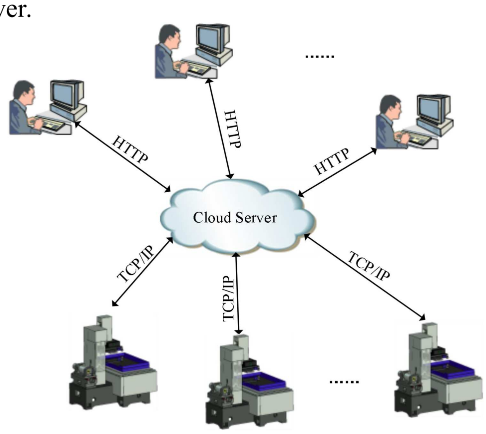


Fig.1 The architecture of the system

An advantage of modular design method is that users can find the fault quickly if there is something wrong with the machine. And as long as it meets the corresponding interface standards, the corresponding module can be directly replaced, such as interpolation module, speed planning module, neural network module, PID control module, etc. In this way, when the user performs the operation on the machine tool, the user can access the website through the browser and then select different combinations of modules to process the workpiece, which makes the control system more flexible and convenient. For WEDM software developers, they can write modules that conform to the interface standards, then post it to the web. Then the user can use the module by downloading and installing it on the corresponding server. This approach provides an open platform for developers and users, which facilitates the development of WEDM software.

Ⅲ. SYSTEM FUNCTION IMPLEMENTATION

A. Cloud Server and Client

A website was built on the cloud server for client access. The website is mainly written in HTML and PHP language. HTML is used to design the front end interface of the website. To efficiently complete the layout of the entire page of the website, the open source bootstrap framework is used for development. And the back end is mainly written in PHP language. The functions to be implemented at the back end of the website are mainly the calculation and analysis of data, such as the training of the relationship model between WEDM processing parameters, and the function of fault prediction and diagnosis. To record some important data, a MySQL database is built on the server. It is used to store the data trained by the network and record the status information of the machine tool, which is convenient for the user to recover to the normal status before the failure of the machine occurs according to the state information at the time.

The overall framework of the website running on the server is shown in Fig. 2.

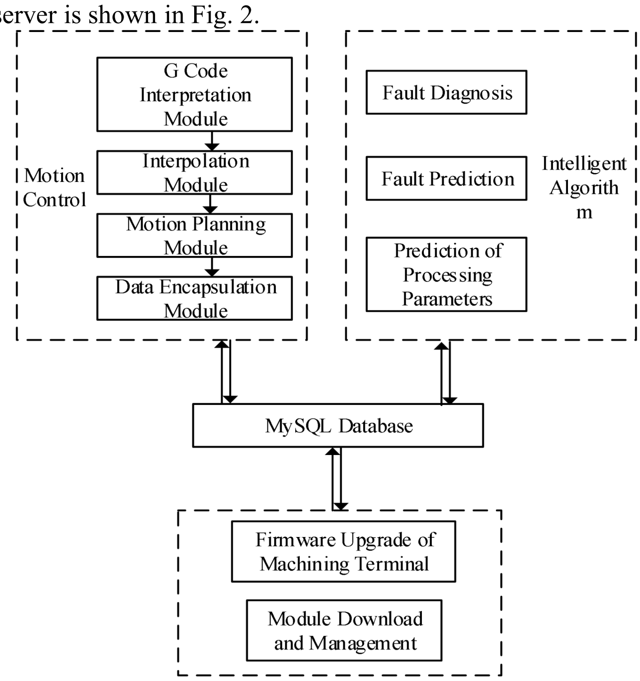


Fig.2 The framework of server modularization design

Different from the traditional WEDM CNC machine tool, in this paper, the CNC system runs on the cloud server, and the used control algorithm is also completed by the server, which reduces the task of the processing terminal. The CNC system is mainly composed of four modules, they are G code interpretation module, trajectory interpolation module, motion planning module and data encapsulation module. G code interpretation module receives G code files transferred from the client and interprets them. According to the interpretation result, trajectory interpolation module calls the interpolation function to generate interpolation data. And then motion planning module makes velocity planning for the interpolated data. Finally, the data encapsulation module is called to encapsulate the motion data information and then send it to the processing terminal.

The schematic diagram of the user's manipulation of the processing terminal is shown in Fig.3. The user sends a request to the server through the browser, then the server sends the request page to the client and displays it in the browser. The default control module is embedded in the server, but if the user would like to process the workpiece according to their own needs, then the corresponding control module can be downloaded and installed. After the module selection is completed, send the processing file to the server, and the server converts the processing file into a motion data stream and sends it to the processing terminal according to the user's selection.

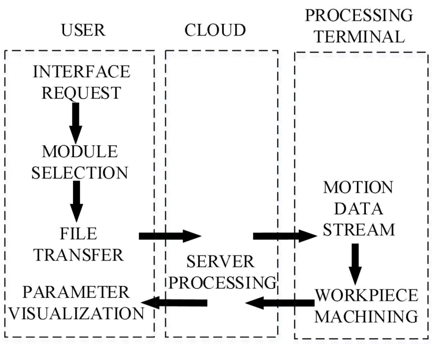


Fig.3 Flow chart of control system operation

The processing terminal and the server are connected by socket. The server can send the movement information of X and Y axis motor and switching signals of other auxiliary equipment to the processing terminal, the processing terminal can also send processing information such as pulse width, pulse interval, servo reference voltage, short circuit rate, open circuit rate, cutting speed, etc. to the server. Based on these data information, processing status, such as short circuit or open circuit, can be identified by machine learning algorithms. And the relationship between these parameters can also be modeled so that the user can predict the corresponding recommended setting values, such as pulse interval and servo reference voltage, which reduces the threshold for the use of electrical processing equipment.

The software implementation frame of the server is shown in Fig. 4. The user clicks the button on the interface to trigger the click event, and runs the script code written by JavaScript, in which changes the color of the button. And then transmits the data that needs to be sent to the backend of the website via Ajax and write the data into database. After the PHP script code running on the server detects the update of database, then the data will be transmitted to the processing terminal through the TCP/IP protocol.

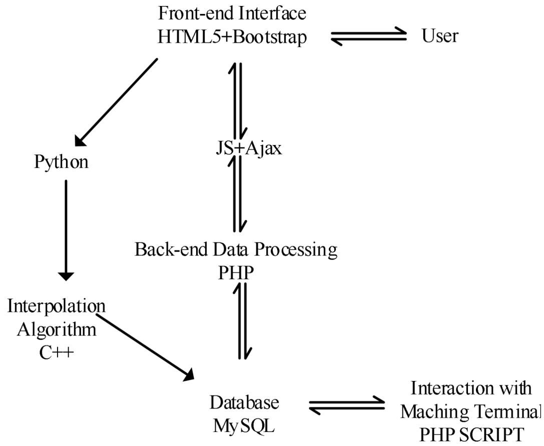


Fig.4 Server software implementation diagram

At present, most G code interpreters and interpolation algorithms are implemented by C language. To reduce the time spent on code rewriting, use Python to call C language functions, which can also help to improve the efficiency of program execution to a certain extent.

After the connection between the server and the processing terminal is established, the user can not only easily replace a module in the control system through the client, but also upgrade the processing terminal program. The processing terminal chip is programmed with a Bootloader program for upgrading firmware through the network. The module replacement and firmware upgrade process is shown in Fig. 5.

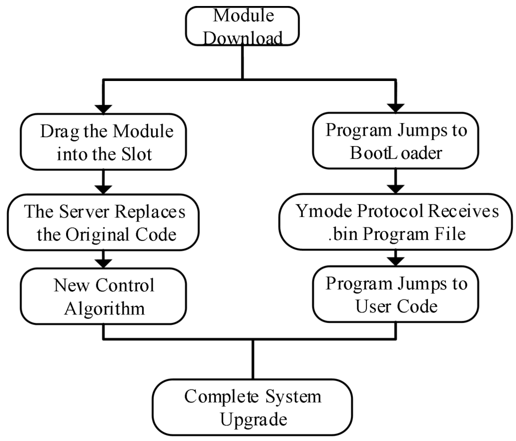


Fig.5 Algorithm module replacement and firmware upgrade process

B. *Processing Terminal Implementation*

The processing terminal mainly accomplishes the motion control of the processing equipment. It includes two tasks. One is to form a closed-loop system with the servo amplifier and the grating ruler, and the other is to interact with the server to convert the corresponding control information into a driving signal to the motor. A structural diagram of the processing terminal is shown as Fig.6. After receiving the data packet sent by the server, the WIFI module stores it in the buffer. The motor motion control section reads the data from the buffer and then sends control commands to STM32F407 to achieve motor motion.

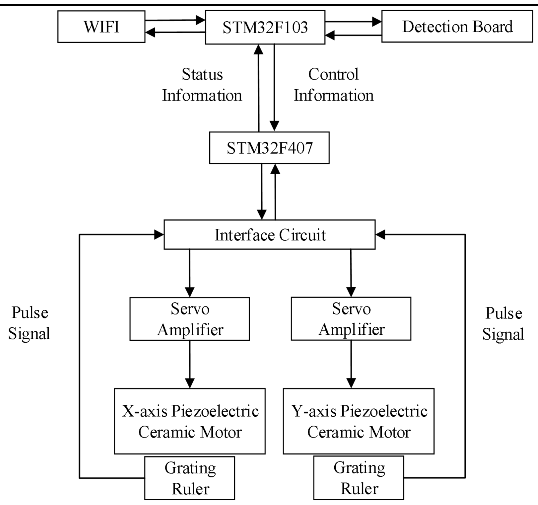


Fig.6 Frame diagram of processing terminal

The entire system requires high real-time performance of motor control, so use a timer interrupt to meet the requirement. That is to say, in the timer interrupt, a control command is sent to STM32F407 to control the motion of the motor. The period of the timer interrupt can be changed in real time to control the speed of the motors.

The resolution of the X and Y axis motors used in this system is 0.1μm. Processing power supply is pulse power. By using four PWMs, eight MOSFETs are controlled. The number of MOSFETs controlled by each PWM is 1, 2, 2, and 3, respectively. The machining current is controlled through combination of MOSFETs. In order to improve circuit stability, the PWM generation circuit is isolated from the main circuit using optocoupler elements. By adjusting PWM pulse width and pulse interval, the adjustment of discharge time and chip removal time is achieved. The short-circuit detection is designed separately from the pulse power supply so as to be mounted on different pulse power supplies, thereby realizing decoupling of the pulse detection circuit and the pulse generation circuit.

EDM has a retraction function in servo control when there is a short circuit during processing. Some systems use reverse interpolation to achieve short circuit retraction. It means that when a short circuit occurs, the original path is retracted. Although this method is feasible, it requires a processor with strong computing power. The system architecture proposed in this paper determines that this approach is not feasible. Because although the server has great advantages in computing, the motion data needs to be transmitted through the network, which takes at least 100ms to complete. When a short circuit occurs, such time is enough to cause damage to the workpiece. Therefore, in this paper the system puts the short circuit retraction function on the processing terminal, and uses the buffer to store data, which helps to solve the retraction problem.

As shown in Fig.7, the processing terminal adopts Ping-Pong buffer structure to reduce network latency and realize short circuit turn back. Data is stored and read through the "input data selection unit" and the "output data selection unit". Suppose that the "input data selection unit" selects the memory chip 1 to store data at a certain time, then the "output data selection unit" selects the memory chip 2 for data output. When the write speed is greater than the read speed, STM32F103 waits for the data to be read. After that, switching is performed, the memory chip 1 is for read, and the memory chip 2 is for writing. The write speed is generally greater than the read speed. In order to prevent the read speed from being greater than the write speed, STM32F103 waits for the end of the write operation, and then the write and read states are switched. Through this method, data stream can be stably output. Even if the delay in data transmission is caused by the network, the normal operation of the system will not be affected in a short time. In addition, in order to reduce the time taken by CPU for data writing and reading, use DMA technology to implement read and write operations to the memory chips.

Considering the short circuit retraction function of the machine tool, the storage space is divided into 4 parts. When a write operation is performed, only half of the storage space of the same chip is written, and the other half is used for retreat when a short circuit occurs or for buffering subsequent motion data. Therefore, at any time during machining process, there is always one space in read state, one space in write state, one space for the retreat of short circuit, and one space for buffering subsequent motion data, which ensures stable operation of the system under normal or short-circuit conditions.

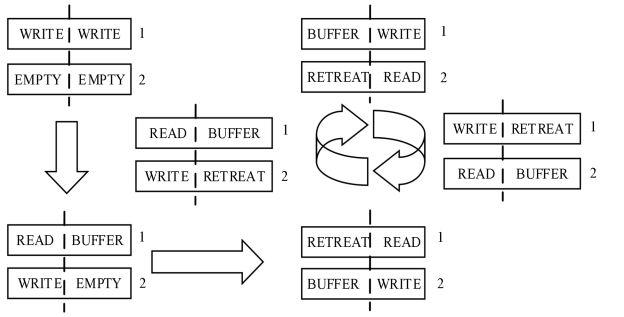


Fig.7 Buffer data read and write flow chart

IV. EXPERIMENTAL VERIFICATION

The cloud-based WEDM control system designed in this paper is experimentally verified on the HITSZ-W1 platform. The prototype is shown in Fig. 8.

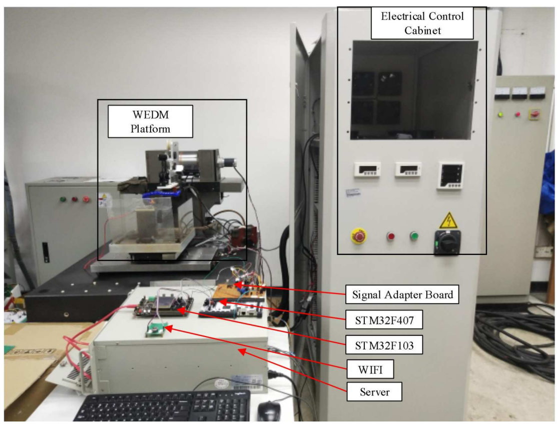


Fig.8 Prototype of cloud-based WEDM control system

Connecting the WEDM machine tool to the designed processing terminal. The server program is running on the PC. The interface is shown in Fig. 9. To verify the feasibility of the system, a workpiece is machined with this system.

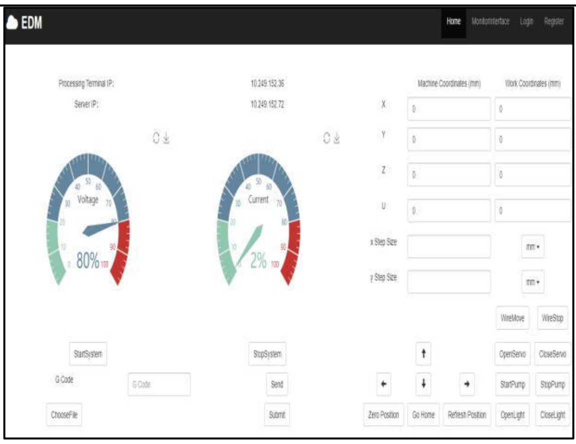


Fig.9 The interface of server operation

Using the system to machine a gear sample on aluminum panel. The feed rate of each axis of the machine tool is 0.5μm per step. The specific processing parameters are shown in Table 1.

During the machining process, processing parameters, such as gap average voltage, short circuit rate, cutting speed, etc. are collected in real time and stored in the cloud. The variation of the sample's processing parameters is shown in Fig.10.

TABLE I
LIST OF PROCESSING PATAMETERS

Item	Value
Thickness of Aluminum plate	3mm
Processing voltage	85V
Peak current	8.5A
Pulse width	10 μs
Pulse interval	10 μs
BLU	0.5 μm

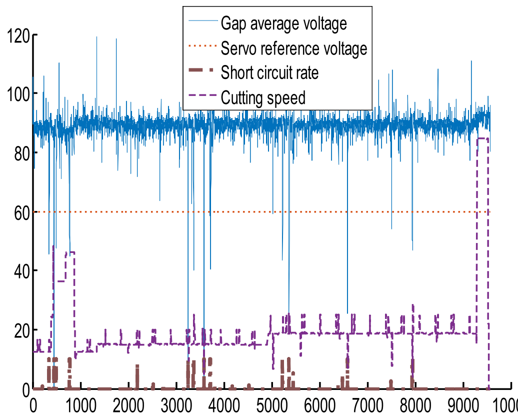
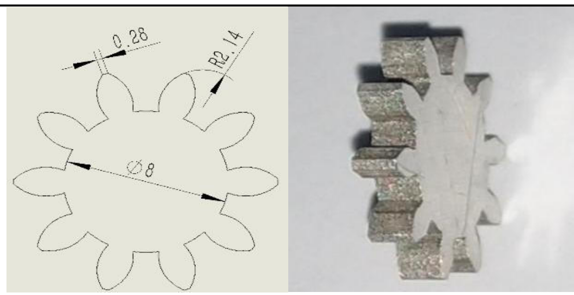


Fig.10 The variation of the collected processing parameters

The schematic view (a) and the actual view(b) of the machined sample are shown in Fig.11. The experiments verified that the system can work normally.



(a) schematic view (b) actual view

Fig.11 Schematic and actual view of the sample

V. CONCLUSION AND FUTURE WORK

In this paper, the architecture of cloud-based WEDM control system is presented. This architecture has four main advantages. First, it saves hardware resources. Traditional WEDM machines need to be equipped with an industrial computer. In this paper an embedded chip can complete the corresponding work. Second, it realizes partial decoupling of hardware and software, which reduces the difficulty of software development and the huge cost of maintenance and upgrade, and also improves the flexibility of design. Third, with the development of AI technology, which requires the support of massive data, this architecture can help to collect data from electrical processing equipment into the cloud, which lays a foundation for the development of intelligent factory. Fourth, the monitoring of the processing equipment is realized by means of a browser, which reduces the requirements on the client device, only needs to have the function of accessing websites.

In the future research, further improvements will be made in the following aspects. First, system security needs to be strengthened, there may be some security risks in the data transmission. Second, using database as a bridge for data transmission occupies more CPU resources, and to some extent, it reduces the speed of data transmission. So the communication method can be changed to a better way. Finally, some machine learning algorithms, such as electrode loss prediction, processing module selection, etc. can be used in server to improve the intelligence of machining process and facilitate users to operate the machine tool.

ACKNOWLEDGMENTS

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