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Design and Application of Inspection Robot Control System Based on Motion Controller

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Abstract: This paper introduces a new motion control system for inspection robot, which can be used to detect and track turbine blades effectively. In the long-term operation process of steam turbine in nuclear power plant, it will not only bear the problems of high temperature and high pressure caused by rotor rotation, but also have to bear the additional stress caused by vibration caused by rotation. These problems may cause damage to the steam turbine rotor, which have a big hidden danger of safety. Therefore, it is important to inspect and evaluate equipment condition frequently. In view of the progress of robotics research, it is suggested to develop a control system of steam turbine rotor autonomous detection robot, in which the DMC-2143 motion controller is used as the control unit of the whole system, the servo motor is the execution unit, and the PC is the support unit. Then, according to the task needs, relevant detection tools are equipped to detect any defects that may exist on the turbine blades. Finally, the defect information is forwarded to the robot's controller for subsequent maintenance work. The fully developed robot was experimentally evaluated on a real-world turbine blade, and the results obtained were very promising. The whole system has significantly improved the inspection quality and efficiency of the turbine rotors in the nuclear power plant, and ensures the safe operation of the turbine rotors in the nuclear power plant.

Keywords: Motion Control, Inspection Robot, Automatic Detection

1. Introduction

During the long-term operation of the nuclear power plant, due to the influence of many factors such as poor neutrality of maintenance and hoisting or operating conditions, it is easy to cause abnormal vibration of the steam turbine rotor, which may cause damage to the root of the turbine rotor blade, such as root cracks, etc [1]. Root cracks will continue to expand upon operation, and even lead to blade breakage. The broken blade fragments are dissociated from the high-speed rotating low-pressure rotor blades, resulting in damage to the entire rotor blade, which is very destructive. In June 2006, Unit 5 of Hamaoka Nuclear Power Plant in Japan was shut down due to the abnormal vibration of the steam turbine. After opening the cylinder, it was found that there was a detached and twisted blade at the end of the low-pressure cylinder B. This blade was the third-stage blade at the end of the rotor. The upper part of the root of the blade started to break with 0-4 mm behind the pin hole, and the fractured part had a certain inclination angle with the top of the pin hole. Since the structure of the low-pressure rotor blade root of the steam turbine of the domestic nuclear power plant is similar to that of the Hamaoka power station in Japan, in order to avoid the domestic nuclear power plant turbine units repeat the Hamaoka nuclear power plant in Japan, it is very important to develop the nondestructive testing technology of the turbine root [2]. This project attempts to design an open inspection robot control system based on motion controller. Its core technology lies in open module architecture and motion servo control system. The overall architecture of the control system takes PC as the support unit, motion controller as the control unit, and servo motor as the execution unit. The LAN communication control method is adopted to realize the high speed linkage of the upper and lower machines, so as to meet the requirements of efficient and real-time inspection control of intelligent vehicles. Based on Microsoft Visual Studio development platform, the functional modules of each system are constructed hierarchically, and the software system is developed.

2. Basic Hardware Platform of Inspection Intelligent Vehicle System

2.1. The Overall Architecture of the System

The inspection intelligent vehicle control system designed in this paper is mainly composed of the upper computer, the lower computer and the servo drive control system. The main structure of the control system is shown in Figure 1.

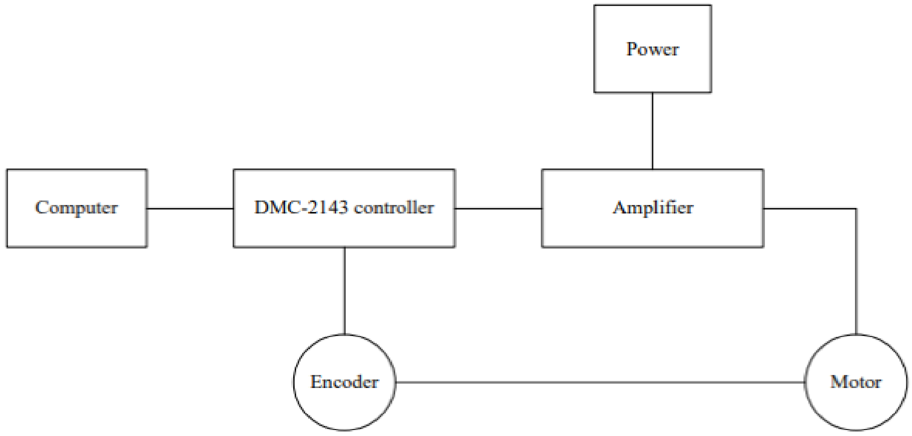

Figure 1. *Control System Components.*

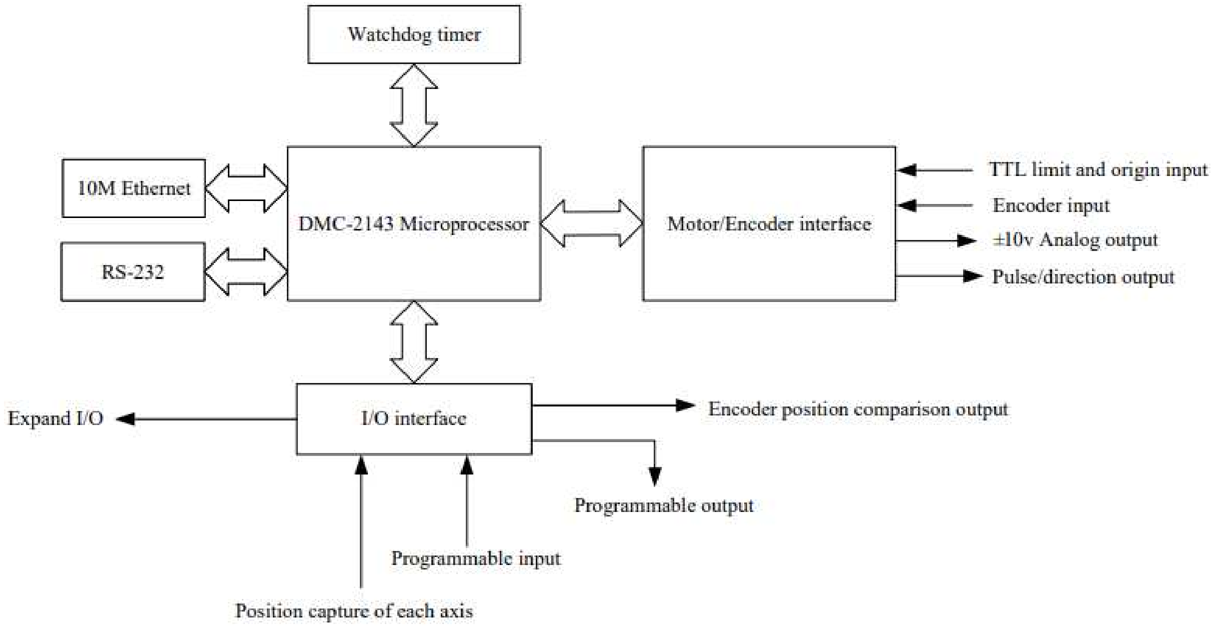

Figure 2. *DMC-2143 Functional Components.*

The control system is mainly used to monitor the movement of the patrol intelligent vehicles, but in order to meet the actual needs of management, it must meet the following characteristics: (1) The controller has high stability, high reliability, and high openness advantages such as flexibility and scalability. (2) The man-machine interface is simple and convenient, and it is easy for operators to understand and operate. (3) It has high real-time performance and so on. Based on the above conditions, the control system of the inspection intelligent vehicle adopts the structure of combining the mobile computer and the controller of the sports vehicle, thus forming the basic hardware structure of the control device. The upper computer adopts a mobile computer, which has the advantages of easy portability, strong control and high efficiency. The DMC-2143 motion controller is used as the lower computer of the intelligent vehicle control system. The DMC-21 series is an economical multi-axis stand-alone controller with faster communication speed, non-volatile memory, faster encoder feedback speed and more complete functions than earlier models. DMC-2143 motion controller provides two communication channels: RS-232 and Ethernet, it provides 4M Flash EEPROM memory for storing application programs, parameters, variables, and arrays [3]. It can deal with complex motion problems and can be widely used in control tasks including point-to-point orientation, vector positioning, combined motion, trajectory motion and so on. The controller can monitor the acceleration and deceleration process of the smart car by reasonably planning the smooth motion trajectory, so that the influence of motion on the mechanical part is greatly reduced. Figure 2 shows the DMC-2143 functional components.

The central processing unit of the DMC-2143 is a dedicated Motorola 68331 series microprocessor with 4M RAM and 4M FLASH. RAM provides storage space for variables, arrays and programs. FLASH provides power-off storage for variables, arrays and programs, and the firmware of the controller is also stored in a flash. For standard servo motor operation, its motor interfaces to generate a ±10V analogs; for sine wave operation, it uses two DA channels to generate 2 ±10V analog; for stepper motor operation, and it generates pulse and direction signals. The communication with the DMC-2143 series motion controller includes a 10M Ethernet and a RS-232 serial port. The baud rate of the serial port is up to 19.2K. It provides an 8-way TTL input, 8-way TTL output interface. In addition, unused secondary encoders can also be used as additional inputs (two per axis). General-purpose input points can also be used for high-speed position capture for each axis. Most importantly, this series of motion controller provides an internal watchdog timer to ensure that the microprocessor works in a normal state. The timer triggers the amplifier to enable output (AMPEN). In the event of a severe failure of the DMC-2143, AMPEN is used to shut down the amplifier output. AMPEN is usually a high level. During power-up, if the microprocessor suspends work, the AMPEN output will become low, and the alarm light will be lit at this time. At this time, the reset operation can be used to make the DMC-2143 work again.

2.2. Hardware Design of Control System

The upper computer of the control system is responsible for the motion monitoring task of the entire intelligent vehicle system, including human-computer interaction, network connection, motion parameter setting, data display and recording, and sending control commands to the motion control card. The motion controller of the lower computer is mainly responsible for the transmission of the motion command of the smart car, the transmission of the pulse command, the processing of the feedback signal and the safety guarantee. The realization of motion controller instructions and the compensation for speed and position is realized through the drive amplifier. As shown in Figure 3 and Figure 4, it is the hardware structure diagram of the intelligent vehicle control system.

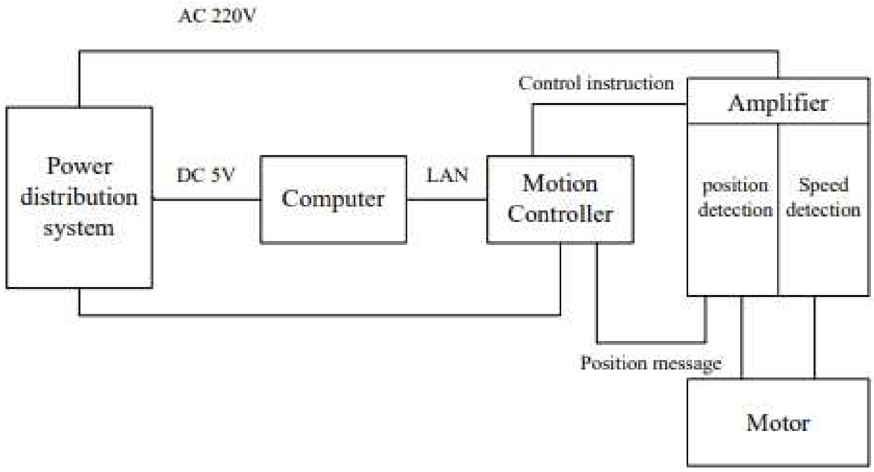

Figure 3. *Control System hardware structure diagram.*

Figure 4. *Inspection robot hardware implementation.*

3. Design of Software Platform for Control System of Inspection Intelligent Vehicle

The inspection robot control system is mainly used to control the operation of non-destructive testing for the outer wall of the steam turbine rotor by the intelligent vehicle. It establishes a network connection with the motion controller of the lower computer through the motion control software of the upper computer, and sends commands of the upper computer to the motor through the motion controller. Complete the automatic tracking motion and fine-tuning motion of the robot. The former ensures the normal operation of the robot according to the established circuit, while the latter can ensure the safety and controllability of the robot during initial debugging and special circumstances. According to the operating environment and operation characteristics of the robot, the software system is developed with Visual Studio 2017 software. Under the .NET framework, the dynamic link library of the motion controller provided by a digital motion control company in Beijing is used. Based on the C# programming language, WinForm technology develops upper computer motion control software [4]. The whole software adopts a modular development method and is packaged into an easy-to-install application program, which is convenient for system expansion and upgrade.

3.1. Software Framework Design of Inspection Robot Control System

In this paper, the inspection robot control system adopts the program design idea of the quantum framework, and integrates the object-oriented design concept. Based on event-driven and active objects, a higher level of encapsulation is carried out, and the application software and control system are reasonably eliminated. The problem of mutual coupling with them, thus realizing the openness and real-time requirements of the system. The quantum framework is equivalent to a lightweight software bus, which mainly undertakes the functions of message exchange and information transfer in the management system, and is the key means to ensure the openness of the robot control system at the level of software requirements [5]. The robot control system in this paper can include multiple modules, such as an I/O logic processing module, interpolation operation module, position control module, coding module and so on. The quantum framework can split the above modules into different active object categories, which can include a quantum framework that "subscribes" to the desired event type or a quantum framework that "publishes" an instance of a thing. The quantum framework is based on the "subscribed" transaction category, "Publish" the event instance to the corresponding active object subscriber. Therefore, in this paper, the quantum framework is designed as a bridge between various modules in the controller to determine the coupling relationship between the functional modules in the controller, and the control software is not dependent on the operating system platform, so it can be used in various Free port and running in the operating system.

Figure 5 shows the operation interface of the inspection robot, which mainly includes network connection, mode selection, parameter set, information display and motion control. Users can set relevant parameters according to their own needs [6].

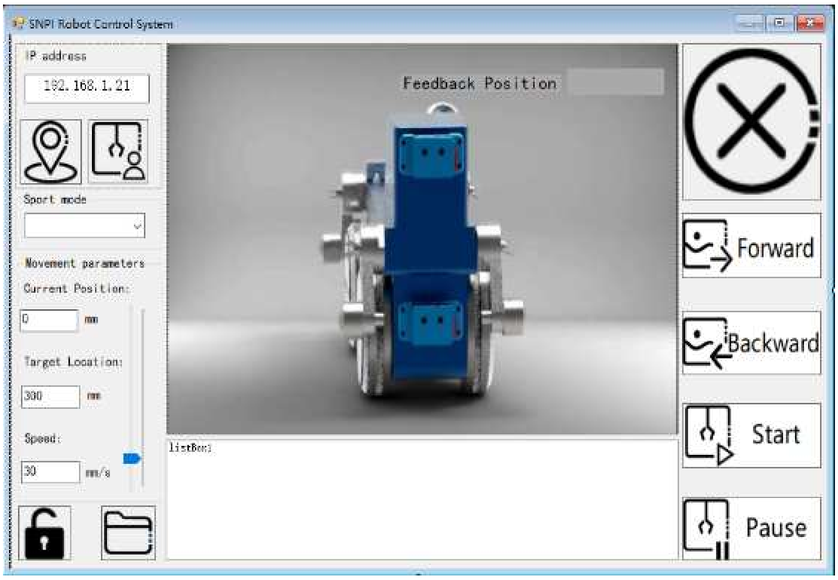

Figure 5. *Operation interface of the inspection robot.*

3.2. Working Mode of Inspection Robot

According to the working state of the inspection robot, the control system presets three motion modes: automatic tracking mode, jog fine-tuning mode and relative motion mode [7].

(1) Automatic tracking mode: In automatic tracking mode, the user can call the robot's operating parameters set in advance by the motion controller to complete a back-and-forth scanning task. After the task is completed, it returns to the initial position. The machine sets motion parameters and limits information to complete the scanning task. In automatic mode, you can click the pause button during the exercise to reset the exercise parameters.

(2) Jog fine-tuning mode: Jog fine-tuning mode is a movement method used when the inspection robot does not run to the specified position. By tapping the jog button, the position of the robot is fine-tuned, and the detection task of the outer wall of the steam turbine rotor is completed.

(3) Relative motion mode: In the relative motion mode, by setting a target position, the robot starts a scanning task. When the target position is reached, the robot stops moving immediately and resets the parameters. Relative motion mode is usually used in conjunction with jogging fine-tuning mode. During the relative movement, the operator can control the robot's inspection and inspection tasks in real time by clicking the pause and resuming buttons.

3.3. Application

The Figure 3 is the main interface diagram of the robot control system software [8]. In a robot inspection and control process, various motion parameters of the robot are set, and the robot's motion instructions and the movement position are issued and completed through the motion controller and encoder. Feedback information is displayed on the main interface, and the parameter information about the robot's motion is saved at the same time. In the automatic tracking mode, the saved motion parameters can be called to complete a round-trip automatic inspection and scanning task. The specific robot inspection operation process is shown in Table 1.

Table 1. *Robot inspection operation process.*

Operating procedures	Process parameters
Wired or wireless transmission	local IP address
Select work mode	Automatic racking or jog fine-tuning or relative motion mode
Movement parameters	Speed or current position or target position
Start working	Location information of scanning points

Figure 6 shows the working environment and working method of the inspection robot under real conditions, so as to facilitate readers to understand its working principle.

Figure 6. *On-site map of the inspection robot.*

4. Common Exceptions and Handling

In the inspection work of the inspection robot, there will inevitably be some abnormal situations, which can be roughly classified into two situations: abnormal network connection and large position deviation errors. The following describes how to resolve both exceptions.

4.1. Abnormal Network Connection

During software operation or during the operation of the inspection robot, the word "ERROR: -1100 device timed out" appears in the information display area, indicating that there is a problem with the network connection between the computer and the controller. We should first use the ping command to test the network situation to see if it is caused by the wrong network environment settings. Then check the local connection status in the lower right corner of the desktop to rule out network interruption caused by hardware damage. Finally, restart the motion controller and reconnect to the network.

4.2. Large Position Deviation

This control software can automatically detect large position deviation errors. When a large position deviation error occurs, the software will automatically pop up a dialog box to alarm, and record it through the information display area. At the same time, it stops all movements and makes the motor enter a non-enable state, which can protect the equipment. And the workpiece will not be caused by dangerous movements such as flying caused by large position deviation. Large position deviations may be caused for the following reasons: If there is no problem with the software settings through inspection, we need to check the hardware. The large position deviation is the position feedback received by the controller, that is, the difference between the encoder return value and the actual value, resulting in a large position deviation. If it is not due to the software not setting the correct control axis, it is basically a problem with the return value of the encoding. At this time, we need to check whether there is no fault in the hardware encoder, which can cause incorrect feedback. Next, check whether the encoder wire in the cable joint has welded quality or For short-circuit, virtual welding and other problems caused by other reasons, finally, check the encoder-related connector cables in the control box.

5. Installation

Table 2. *Instruments and parts used to build robot.*

SI	Instrument list	Quantity	Remark
1	DMC-2143 Controller	1	required
2	ICM20105T Terminal Board	1 or 2	recommend
3	RS232 cable	1	optional
4	Ethernet cable	1	optional
5	DC power	1	required
6	DB-28040 I/O Expansion Card	1	optional
7	CB-50-80	1	optional
8	CAB-80	1	optional
9	IOM-1964-80	1	optional
10	Analog input line	1	optional

1) Determine motor configuration: Standard Servo Motor Amplifier Operating Mode or Stepper motor amplifier working mode .DMC-2143 has been set to the standard servo motor amplifier working mode before leaving the factory, no need to do hardware and software settings. In order to configure the DMC-2143 to work as a stepper motor, a jumper for setting the stepper motor is required for each axis in hardware, and in software configuration, the corresponding axis must be set to stepper motor.
2) Set communication frequency: The communication frequency of RS-232 is set through the jumper on the control board. There are two jumpers 1200 and 9600 on JP2. The setting of the communication frequency is as follows.

Table 3. *Communication frequency setting table.*

1200	9600	Baud rate
Short	open	1200
open	Short	9600
open	open	19200

3) Install communication softwares: First mount the CD-ROM disk to your computer, then run the CD-ROM software and select "DMC SmartTerm". At this point, the motion controller integrated terminal tool software is installed on your computer and used to establish communication between the computer and the controller.
4) Connecting Drives and Encoders: Starting with the A-axis encoder. After confirming that the connection is correct, turn the motor shaft and use the command TPA <Enter> to query the position. The value read back by the controller will change from the rotation of the motor. And so on.
5) Connect the Servo Motor: Motors and encoders can be configured in torque or speed mode. In torque mode, the amplifier gain should be the maximum current required for a 10V command voltage signal. In speed mode, the 10V commands voltage signal should correspond to the maximum speed of the motor.
6) Adjust Servo Gain: Adjust the relevant parameters required when using the servo motor to optimize the system performance. Getting fast and precise responsive performance.

6. Similar Projects

There are multiple projects, in progress and completed, relating to Inspection robot.

One of the projects, using the PC as the platform, realizes the coordinated control of multiple servo motors, so that the terminal manipulator can complete the dynamic interpolation motion of any trajectory in the three-dimensional space, and satisfies the system goals of multi-station, multi-task and multi-request. Making the system highly portable and open [9].

The other is based on the VB programming environment, using a control system composed of a motion control board and a PC, which solves the problem of the point-to-point positioning control performance of the rotary cultivator in the key process of the knife shaft and the knife welding process in the production process of the small enterprise. It has the characteristics of reconfigurable performance, easy to implement special data processing and to meet specific process paths. Improve the stability of the welding process and reduce the labor intensity of workers [10].

A motion controller, which changes the control strategy of the CAN servo stepping driver dynamically according to the rotational speed. The proposed method of developing motion controllers with an ARM microcomputer allows reducing the time and financial costs of fully integrating the drive control module into the CNC system at the initial stage. The current project implementation is the interaction of programmable and hardware components: the motion controller is used to control the movement of the CAN drives, thus providing the interconnection of the CNC system and the drives [11].

This article aims to realize the diversity and excellent scalability of open robotic systems with multiple degrees of freedom, real-time performance, and high reliability. The system is an open control system, so other users can use new control technology, while software technology and sensor technology can further develop and expand new functional modules [12].

Indoor robot motion controller, based on a complex combination of software, hardware and mechanics. The hardware includes a single-chip microcomputer module, a power supply module, a motor drive module, a servo module, and a speed detection module; the software includes a single-chip initialization program, which uses a PID control algorithm to control the speed, and a PWM motor control by changing the duty cycle. The camera is used for image acquisition module [13].

The CNC machine tool system based on the computer host and the PMAC motion controller obtains information through the digital-analog conversion of the upper computer, and performs signal processing and analysis and compensation for the machining error to improve the machining and grinding accuracy [14].

Aiming at the problem of poor compatibility caused by binding a certain motion control card to many CNC systems, the CNC system architecture of "PC+motion controller" is adopted, and a "motion control card common" is added between the man-machine interface and various motion control cards. Interface module "intermediate layer, developed a set of V-cutting machine CNC system compatible with various motion control cards [15].

7. Conclusion

Compared with the traditional nuclear power plant inspection robot, our project becomes smaller and has a larger inspection area. Can carry a variety of inspection tools, so that the previous tedious replacement work becomes simple and efficient; The whole device has a strong climbing force and superior waterproof performance, to ensure the intelligent vehicle in the coupled water immersion environment for continuous and efficient operation. Through a series of innovations and practices, the inspection quality and efficiency of the automatic turbine blade inspection system have been significantly improved after the upgrade. At the same time, the high degree of automation reduces the labor cost to the maximum extent, avoids the radiation harm caused by the work of nuclear power plant, protects the health of workers, and escorts the safe operation of nuclear turbine rotors. Software and circuit designs are available free of charge upon contacting the author. The author will be honored if his work contributes to any technological advancement that benefits humanity.

Future Scope

1) Simplify and improve the body structure of the inspection robot to make it lighter and easier to carry.
2) Upgrade the battery pack to increase its runtime.
3) Added more capable and sensitive sensors to detect greater distances.
4) Integrate advanced image processing system and data analysis system to improve inspection efficiency.
5) Encapsulated into executable application software to improve its portability and extensiveness.

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