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Radioactive Waste Lead Canister Drumming Nondestructive Analysis System Software Development

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Abstract

In order to further improve the efficiency of non-destructive testing of empty drums in lead canisters holding nuclear waste, to improve the safety assurance of lead canisters in the nuclear industry, and to promote the efficient application in the field of nuclear waste treatment, the manual and automated control of the mobile robot, the parsing of scanning data from random points of lead canisters, the doing of path planning for the mobile robot so as to adaptive scanning, and the displaying of scanning data in a 2D/3D manner in a visual way are presented on the The software platform. The platform experiments and theoretical calculations complement each other to realize the fully automated inspection and imaging of lead cans.

Keywords

Empty Drums; Non-Destructive Testing; Mobile Robots; Path Planning.

1. Introduction

With the wide application of nuclear technology and the nuclear industry in important fields such as medical care, aerospace and agriculture, large quantities of medium- and low-level radioactive solid nuclear wastes are constantly being generated. Unlike general industrial waste, nuclear waste can only be gradually transformed into ordinary industrial waste through its own decay. According to the relevant national regulations, low and medium radioactive solid waste can be disposed of near the surface, while high-radioactive and alpha solid nuclear waste needs to be disposed of centrally at a certain depth in the geological layer. The national standard stipulates that the dose rate of waste packaging containers should be less than 2 mSv/h at the surface and less than 0. 1 mSv/h at 1 m from the surface after the waste packaging containers are capped.[1-3] It is necessary to test the quality of nuclear waste containers to guarantee the safety of nuclear waste and to prevent managers and operators from being jeopardized.

Nuclear power plants in order to consider the cost and the storage rate of existing materials, the use of lead cans to store nuclear waste as an effective container, due to the large size of the lead cans must be used in the way of casting processing, in the process of processing there is inevitably air into the lead cans caused by the phenomenon of drumming, the detection of drumming in the lead cans in the size of the drum, whether or not to effectively shielding of radiation, the storage of nuclear waste, the safety of the treatment is critical.[4] Therefore, the state of the quality of nuclear waste containers, construction materials and other aspects of hard regulations, in the storage of nuclear waste canister construction, put into use before and after a period of time, respectively, non-destructive testing, until the canister decommissioning.[5]

In the process of testing nuclear waste containers, γ-ray testing has an important application value in the field of nondestructive testing. The principle is that gamma rays produce attenuation when they penetrate the material.[6] The use of gamma rays penetrate different substances with different attenuation, according to the detector to detect the energy after the attenuation of gamma rays, so as

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to obtain the density of the object to be detected and cavities, etc.[7] Gao Yang et al. investigated the problems such as image acquisition and defect description when using X-rays for NDT .[8]Rajsiri et al. investigated the NDT method for the welding fabrication process of pressure vessels under low temperature environment.[9] Radiographic inspection has accurate results, high inspection efficiency, and mature technology, but it requires the operator to have a very high level of professionalism, and the rays can cause harm to the human body.

2. Quality Testing of Nuclear Waste Containers

(1) Manual detection

Manual detection. Artificial detection refers to detectors based on work experience and knowledge using detectors for detection, artificial detection can be detected at any location of the target tank, but can not guarantee the accuracy of the detection process and the accuracy of the results, and there is a certain amount of radioactive material in the detection process, which is hazardous.

(2) Fixed equipment detection

Fixed equipment refers to the target tank customized corresponding equipment, such as for cylindrical tanks using centering circular equipment for detection. The use of such equipment, a single tank state, high detection efficiency, occupies little space, improve the safety of inspectors, and detection accuracy can be guaranteed, but for a variety of tank state, high cost, loading and unloading equipment between multiple tanks has become a problem, resulting in a reduction in detection efficiency.

(3) Mobile robotic arm detection

The use of mobile robots, robotic arms and detectors combined, can effectively solve the shortcomings of manual detection and fixed equipment detection. In the case of manual control, for the target tank can have a variety of detection paths, and high precision, occupies a small space, detection efficiency has been greatly improved, do not need to repeat the tedious loading and unloading work of the detector, only need to move the robot arm for remote positioning can be, the efficiency of the detector staff can be greatly enhanced and safety issues can be a strong guarantee.

Lead canisters have to store nuclear waste stably for a long period of time, and under the environment of strong radiation, it is extremely important for the stable operation of the nuclear power plant, people's life safety, environmental safety, property safety and so on whether its mechanical properties, radiation resistance, structural properties and so on are complete, and whether it complies with the integrity requirements during the service period. For this reason, the state has strict requirements for the construction quality of nuclear waste storage tanks in nuclear power plants. The canisters of nuclear power plants are usually divided into vertical, horizontal and rectangular, because each state of the canisters need different equipment to detect, so the use of mobile robotic arm instead of different equipment to detect, improve the detection efficiency of the lead canisters, can be detected on any state of the canisters to improve the safety of the operator.

3. Based on the Mobile Robotic Arm to Realize the Construction of the Hardware System

(1) Robot mobile platform system architecture design

The robot mobile platform is mainly divided into two parts: the hardware system and the software system, and the structure is shown in Fig. 1.

The hardware system includes power supply module and motion control module. Its remote control module includes a remote lever and CAN bus protocol for data transmission, which can realize the remote remote control of the mobile platform.

The software system includes the bottom software and the upper computer software. The bottom layer software includes the remote control part of the program to carry out the movement control of the robot. The underlying data and the host computer send commands to the corresponding controller through the Ethernet bus interface in the form of command forwarding. The upper computer software

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mainly realizes the setting of the movement parameters of the mobile platform, as well as the generation of the path and the positioning of the platform. Among them, the parameter setting mainly includes running segment parameter setting, conversion PID parameter setting, and right-angle turn parameter setting.

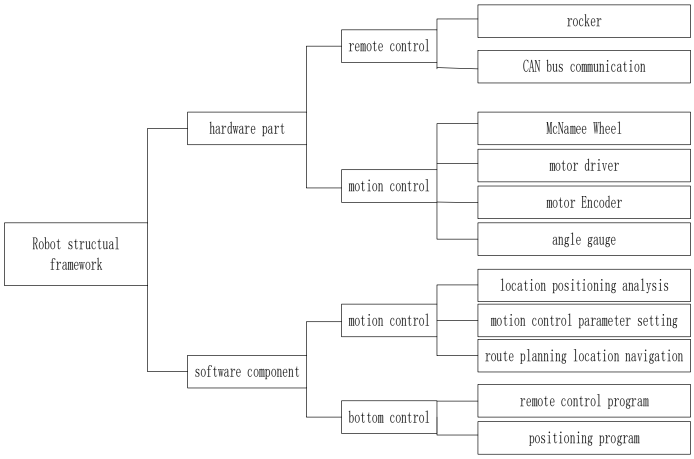

Fig. 1 Block diagram of robot platform structure

(2) Robot structure

Maximum activity radius: 1300~1600mm (planned according to the height of the mechanical car);

Base rotation working range ±360°;

Arm 1 rotation working range ±120° minimum;

Arm 2 rotation working range ±360°;

Minimum ±180° working range of gripper rotation.

Fig. 2 Structure of robotic arm

(3) Gamma radiation detector

Ray type: γ;

Detector type: plastic scintillator + GM tube composite probe;

Effective measurement range:

Plastic scintillator: 0.03 μSv/h～200 μSv/h;

GM tube: 10 μSv/h～100 mSv/h;

Relative intrinsic error: not more than ±15%;

Energy response range: 25 keV ~ 2 MeV;

Response time: ≤5 seconds (5 μSv/h);

Communication interface: Ethernet;

Alarm function: dose equivalent rate exceeds the threshold, detector failure, detector blocking;

Power supply: DC 9 ~ 12V 1000 mA (controller host or power adapter);

Operating environment: temperature -10℃～40℃, humidity ≤90%RH (+40℃).

(4) Based on the mobile robotic arm to realize the different state of the tank path planning

Vertical cylindrical tank, robotic arm carrying power trolley using McNamee wheel design, the use of McNamee wheel can be a full range of Angle of movement, carrying the robotic arm around the vertical cylindrical tank to do the circular motion, the vertical cylindrical tank different angles for detection. Vehicle-mounted robotic arm on the tank three angles of detection of the positional relationship diagram shown in Fig. 3.

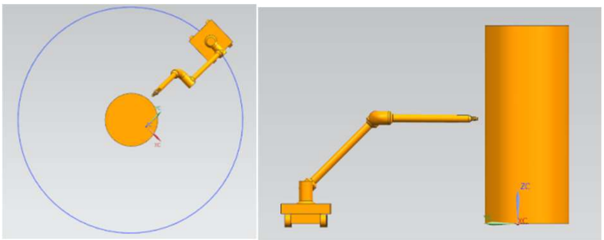

Fig. 3 Position of the robotic arm for vertical tank detection (left) and vertical detection (right).

In each cycle path, the robotic arm moves to a fixed angle and randomly detects points in the vertical direction of the vertical cylindrical tank, scanning sequentially from the bottom to the top of the tank according to different angles.

Horizontal cylindrical tanks. robotic arm in each cycle path, first of all, the tank and the ground contact is set to zero point, the establishment of XYZ coordinate system, the detector according to the next instruction position for the horizontal cylindrical tanks and horizontal cylindrical tanks aligned with the central axis, in order to be perpendicular to the detection of the horizontal cylindrical tanks, at the same time the robotic arm according to the position of the coordinates of the movement, and ultimately, the detector and the horizontal cylindrical tanks in the central axis of the calibration again, calibration is complete, after the mechanical After the calibration, the robot arm mobile vehicle moves on the planned path and randomly detects the points on the horizontal cylindrical tank on the same horizontal line. Mechanical vehicle and robotic arm on the horizontal tank in the same level of the path of the detection position as shown in Fig. 4, the blue line for the path of the moving car planning.

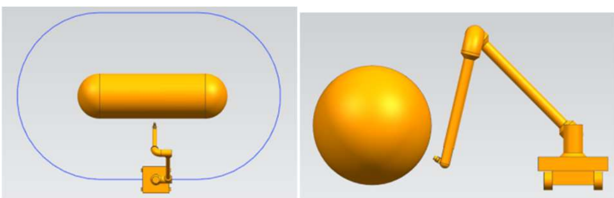

Fig. 4 Position and path planning of robotic arm for horizontal tank detection

Rectangular tanks. When the robot arm detects the rectangular tank, it establishes a coordinate system for the rectangular tank, and first detects the four sides of the rectangular tank, and the robot arm and detector arrive at the coordinate position, and detects in the perpendicular direction of the position of the specified coordinate point on the side, as shown in Fig. 5.

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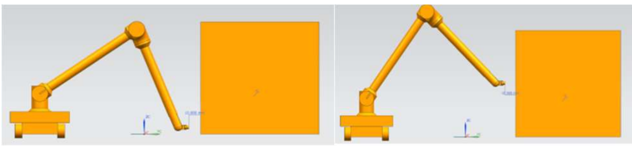

Fig. 5 robotic arm on the rectangular tank in the vertical direction of the detection of the position of the map

Then move on the horizontal route, change the coordinate value on the horizontal route and repeat the detection in the vertical direction. Rectangular tank side detection is completed, and then the trolley to reach the other side, the trolley does not need to rotate the direction of the mechanical arm base rotated 90 °, the movement of the trolley to reach the corner, change the direction of the forward movement, to reach the other side of the specified coordinate point, cycle before the action shown in Fig. 6, the blue line represents the mechanical arm trolley moving route.

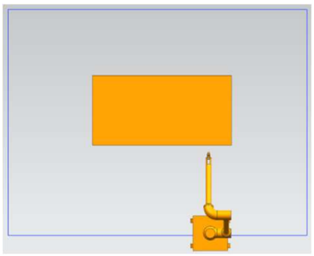

Fig. 6 Position and path planning of the robotic arm for the detection of rectangular tanks

After completing the inspection of the sides of the rectangular tank, return to the starting position and perform the inspection of the top surface of the rectangular tank. Similarly move back and forth within an area until the detection is complete. The position of the robotic arm on the top of the rectangular tank detection is shown in Fig. 7. The three-dimensional view of the position of the robot arm detector on the tank is shown in Fig. 8.

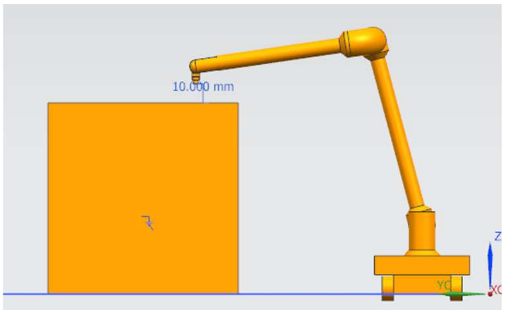

Fig. 7 Position of the robotic arm probing the top of a rectangular tank

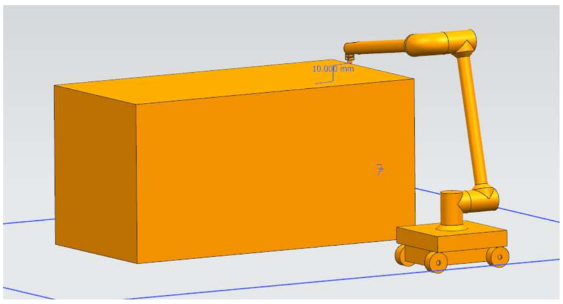

Fig. 8 Three-dimensional view of the position of the robotic arm probing a rectangular tank

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4. Design of Non-destructive Analysis Software System for Non-destructive Testing of Lead Canister Cavitation of Radioactive Wastes

(1) Software architecture and control logic

Pb tank detection and analysis software system consists of control and lower computer hardware communication, upper computer software to control the movement of equipment, data acquisition and analysis, human-computer interaction interface and other components.

Pb tank detection and analysis software system to the computer as the core, need to complete the moving trolley and robotic arm movement path control, detector rotation angle control, acquisition and transmission of detection data and visualization display and other functions, which the movement of the trolley, the robotic arm and the detector control is for the surface of the tank at different points of the detection scanning, the detection data and the position of the arm data back to the computer software, ready for the visualization of data display. Pb tank detection and analysis software system architecture is shown in Fig. 9.

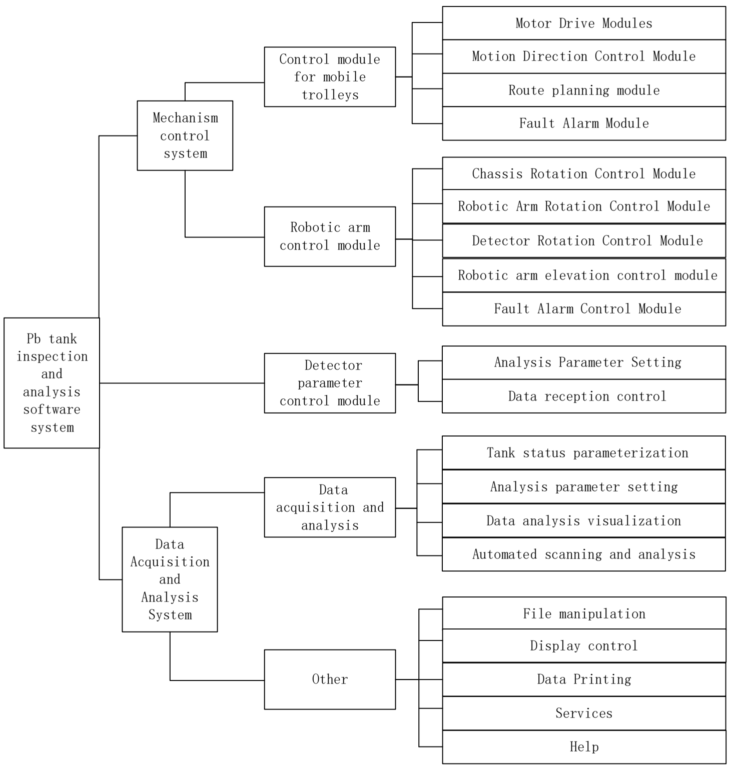

Fig. 9 Pb canister detection and analysis software system architecture diagram

The trolley controller and robotic arm controller interact with the host computer software for command interaction and real-time data transmission and processing.

When the trolley controller and the robotic arm controller are turned on at the same time, they first carry out the turn-on delay, configure the timer and other functional modules, and then enter the waiting state, waiting for the host computer to connect with the on-board controller module. After the initialization configuration is completed, when the docking is successful, the host computer sends control commands, the trolley controller and the robotic arm controller just wait for the start running command, and the host computer carries out the following reaction:

Guidance motion control. The upper computer acquires the tank status data, selects the corresponding planning path diagram, packages the motor speed, sensor angle and other parameters under the planning path diagram and sends them to the controller to make corresponding automated motion control.

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Specify the position information. Establish a three dimensional coordinate system for the target tank before detection, receive the current position information sent from the controller of the robotic arm, and the detection data information from the sensors, and carry out data processing in the software of the upper computer.

Receive remote control data. Judge the remote control mode as manual or automatic mode, when in manual remote control mode, receive and send XYZ axis data in real time, respectively, the speed value of the four motor drives are calculated and sent to the trolley controller.

Send measurement data parameters. The upper computer acquires the set sensor measurement parameter data, sends the data to the sensor, and the sensor works and returns the measurement data.

Get sensor data. Turn on the timer, when the timing time arrives, send the command to each sensor module to obtain data, including robot position information, sensor angle information and sensor analysis of the measured value data information, sent by the communication module in the sensor to the host computer for processing, the host computer will get the data to analyze and display as a 2D/3D diagram.

(2) Communications protocol

Each joint actuator of the robot arm is connected to the robot arm controller via CAN bus, each actuator of the robot is connected to the trolley controller via CAN bus, and the trolley controller and the robot arm controller communicate with the total controller using RS232 to RS485 bus protocol. And then through the Ethernet to communicate with the PC host computer, the controller plays the role of Ethernet and CAN bus communication bridge to each other.

The serial communication module of the master controller interacts with the host computer using the Ethernet protocol for communication. The interface sends commands to the corresponding servo controllers in the form of command forwarding, the servo controllers send commands to the corresponding master controllers, and the master controllers drive the corresponding motors. At the same time, the host computer receives the feedback information from the servo controller or actively reads the status register information of the servo controller to track and deal with the abnormality in real time, which forms a closed-loop control system and ensures the safety of the mechanical device and the operator. In addition to online control, the main controller can also be operated manually directly by offline control to complete the positioning operation.

The trolley controller and robotic arm controller communicate with the encoder board to obtain the current trolley and robotic arm position information using the standard Modbus-RTU communication protocol.

(3) Main interface of the software

The menu bar in the main interface is roughly divided into 4 sections, which are modules for file operation, robot arm control, robot control, parameter setting, and image operation. Each module is divided into different pages, and different pages correspond to different functional options. The file operation includes the functions of opening file, saving file, saving another file, printing, etc.The robotic arm control includes the functions of controlling the motion parameters and setting up the initial axes. The data visualization area in the main interface can be switched in the mode of two-dimensional or three-dimensional diagrams. There is an equipment status display function on the main interface to better monitor the equipment operation status. In the motion control function, the position coordinate parameters of the robot and the rotation parameters of the robotic arm can be displayed in real time, and the buttons for controlling the robot's up, down, left, right, and rotation and the buttons for controlling the robotic arm's up, down, left, right, and rotation can be added, so that the equipment's switching on and off, the reset of the axes, the adjustment of the zero, the switching between the manual mode and the automatic mode, and the setting of the target position parameters can be manually set, etc. The initial setting of parameters includes the setting of path planning. The initial setting of parameters includes the setting of path planning, detector detection parameters, robot moving speed and other parameters.

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5. Conclusion

Lead canisters, as nuclear waste containers in nuclear power plants, are essential equipment during the service period of nuclear power plants and are of great significance. As a nuclear waste boundary, lead canisters need to be shielded from radioactive substances to prevent the leakage of radioactive substances in nuclear waste. When the canister is inspected, the radioactive source is strongly radioactive and cannot be approached by personnel, so its inspection needs to be carried out by a remote-controlled nondestructive testing robot. The good or bad control software of the lead canister NDT robot directly affects the operation of the operator, the life and economic safety of the country and the people. Therefore, the quality inspection of the equipment holding nuclear waste is crucial for the safety of radioactive workers and the prevention of nuclear leakage, and the quality inspection of lead canisters for storing nuclear waste with γ-ray detectors and radioactive sources and the design of software has become a very important and urgent issue.

Acknowledgments

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References

[1] Radiation protection principles for disposal of solid radioactive waste[M]. ICRP Publication 46, 1983.

[2] Radioactive waste management A status report[R]. IAEA, 1985.

[3] Xide Li, Xingfu Liu, Kai Wang. Quantitative Detection of the Defects in Thin-Walled Pressure Vessels with Holography and Shearing Speckle Interferometry[J]. Journal of Nondestructive Evaluation, 2002, 21(3).

[4] Supphachan Rajsiri, Kanokporn Penpondee, Sittiphun Tuntawiroon. Development of Grounding Device to Reduce Current Variation in Submerged Arc Welding Process for Pressure Vessel Fabrication[J]. Advanced Materials Research, 2014, 3545(1043-1043).

[5] MD Meyer, TE Katayanagi. Holographic Examination of a Composite Pressure Vessel[J]. Journal of Testing and Evaluation, 1977, 5(1).

[6] Lunhui Xu, Fan Ye, and Yanguo Huang."Study on Autonomous Path Planning by Mobile Robot for Road Nondestructive Testing Based on GPS".Computer and Computing Technologies in Agriculture IV--Proceedings of 4th IFIP TC 12 Conference(CCTA2010) Part IV.Ed. , 2010, 336-347.

[7] XuL, Ye F, Huang Y. Study on Autonomous Path Planning by Mobile Robot for Road Nondestructive Testing Based on GPS[C]// Computer & Computing Technologies in Agriculture Iv-ifip Tc 12 Conference. DBLP, 2010.

[8] Joseph, Hashem, Erich, etal. Theoretical neutron damage calculations in industrial roboticmanipulators used for non-destructive imaging applications[J]. Progress in Nuclear Energy, 2017.

[9] Ahmed A , Coulbeck L , Castellazzi A , etal. Design and test of a PCB Rogowski coil forvery high dI/dt detection[C]// EPE/ PEMC. IEEE, 2012.