Design and Application of Single-Arm Live Working Robot System on Transmission Line

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Abstract. The power transmission line live working robot walks on the power transmission line through wheels. The robot arm and its end tools carried by the robot body can assist or even replace the manual implementation of live inspection and operation of the power transmission line. It has important theoretical significance and practical application value for improving work efficiency and solving dangerous problems in the operation process. In this paper, a single-arm live working robot is designed and developed for a variety of maintenance tasks on transmission lines. At the same time, a method of autonomous end reconfiguration on transmission line is proposed, so as to automatically realize transmission line inspections and live operation. The robot physical model and the motion planning of the robot manipulator arm for the typical fittings maintenance operation are given. The physical prototype system of the live working robot is developed through the system integration design. Finally, related live working experiments were carried out on the simulation test line so as to verify the feasibility and effectiveness of the single-arm live working robot realize the inspection operation of the power transmission line. The research in this article has important theoretical significance and practical application value for intelligent operation and maintenance management of transmission grids.

Keywords: Transmission line; single-arm robot; physical model; motion planning; operation experiment

1. Introduction

High-voltage transmission lines are exposed to the outside, long-term exposure to wind and sun and facing with severe weather conditions such as violent storms, lightning and thunder, and often damages to transmission lines or their fittings, such as damage to insulator strings, displacement of dampers, and broken wires, loose strands, tension clamp drainage plate bolts, etc. During the long-term grid operation, the transmission line insulators will be affected by environmental factors such as lightning, pollution, ice and snow, high humidity, and temperature differences. They are electrically exposed to strong electric fields, lightning impulse currents, and power frequency arc
currents. The insulator has to bear long-term working load, comprehensive load, wire galloping and other mechanical forces, which will cause the insulator insulation performance and mechanical performance decline. In more serious cases, it will cause long-term and large-scale power outages, which will seriously affect the safe operation of the power system. The tension clamp drainage plate bolts will loosen due to the vibration of the wire, which will increase the resistance due to the false contact. When the temperature of the drainage plate rises, the oxidation of the contact surface is strengthened, and the drainage plate will be burned and a disconnection accident will occur. Foreign objects such as kites (wires), plastics, ropes/cables, etc are entangled and hung on the wires of high-voltage transmission lines, and their dampness leads to deterioration of insulation, which directly causes single-phase grounding and inter-phase short-circuit failures of high-voltage transmission lines; and the damage and disconnection of the wires. It can reduce the current carrying capacity and cause disconnection accidents.

The common live working items mainly include live replacement of insulators [1], live replacement of dampers [2], wire repairing [3], live tightening strain clamp drainage plate bolts [4-5], fittings of pins [6]. At present, the maintenance method of power transmission lines is mainly manual maintenance. For example, when the insulator is replaced manually, the live working personnel are at the equipotential work, and the insulator is replaced with the help of live working tools. However, when the line spacing is too small, the maintenance personnel must move the human body into the live part along the insulator or put it in a hanging basket. This process will cause a short circuit to the ground, and threaten the personal safety of the maintenance personnel, which seriously restrict the smooth progress of the live maintenance operation. Therefore, manual operation methods have become increasingly difficult to meet the needs of modern power grid security stability and rapid economic and social development. Based on this, the research on live working robots instead of manual maintenance operations, the use of drones to assist robots to complete the online and offline, through the self-reconfiguration of different terminal lines to carry out the corresponding live work, the use of the modular design of the robot system to achieve rapid disassembly and reorganization of the robot which convenient for field transportation. It can not only improve the work efficiency, but also reduce the labor intensity of the workers and ensure the safety of the workers to the greatest extent.

2. Working Environment and Task Analysis of Robot

The working environment of the robot for live working on the power transmission line is shown in figure 1. It is mainly composed of three parts, the robot, the tower and the transmission line, and the typical fittings on the transmission line. Among them, the robot can walk on the transmission line by wheeled movement, and realize the maintenance work of the transmission line through the robot arm and the end tool on the body. The main maintenance work on line is the fastening of the drainage plate bolts. The main operation method is through clamp the head of the bolt with one manipulator, and align the nut with the other manipulator, then perform the nut-tightening operation. Another type of maintenance on line is the replacement of the damper. This kind of operation is similar to the tightening operation of the drainage plate. The key is to loosen and tighten the damper bolts so as to realize the replacement of the damper on line. The third type of transmission line maintenance operation is the insulator replacement operation. The key to the insulator replacement operation is to push out the W pin inside the insulator ball head to place the fixed insulator in a free state so as to facilitate the replacement operation. It can be seen from these three typical power transmission line live work tasks that all joints of the single-arm live work robot need to be coordinated to complete the work task.
3. Design of Modular Robot System for Live Working on Transmission Line

3.1. The Overall Architecture of the Robot Operation System

The modular live working robot system platform and its quick disassembly and reconstruction method is to adapt to the robot field operation environment and facilitate the transportation of the robot system in the field environment. When transporting on the road and in the field, each mode is divided separately. The rapid modular reconstruction of the robot system during field application can effectively reduce the unit weight of the robot. At the same time, different execution systems can be integrated according to different tasks. According to the practical technical requirements of live working robots and the principle of functional modular design, the complete live working robot system consists of a robot platform with automatic on-line, walking and obstacle-crossing, a drone auxiliary lanyard device, assisting robot arms, and an integrated execution system. The five-part composition of the ground control base station is shown in figure 2.
3.2. Design of the Robot Body System
In the above five modules, the robot platform, the robot arm system, and the integrated execution system can be reconstructed to obtain the live robot operation system, which is also the core part of the entire system. The operation system consists of the robot body, tool library, omni-directional manipulator and reconfigurable end. The physical configuration is shown in figure 3. It is mainly composed of a machine body, a walking manipulator, a walking wheel mechanism, a pinch wheel, a lifting mechanism, a manipulator moving mechanism, a brake, and an equipotential wheel. The two mechanical arms are arranged antisymmetrically at both ends of the body through joint motors, and the walking wheels are connected with the mechanical arms and walk along the wires. There is a pressure wheel and an equipotential wheel that increase friction with the wire under the walking wheel and protect the wire to meet the equipotential operation capability of the robot and ensure that the robot is always equipotential with the wire. The brake is designed between the pressure wheel and the equipotential wheel to meet the parking stability of the robot. The lifting mechanism is composed of a winch, an insulating rope, an electromagnet and an automatic separation hook. It is installed at an appropriate position in the middle of the robot body. The electromagnet is equipped with the upper end of the automatic separation hook, and the electromagnet is connected to the separate iron plate through the adsorption type when going up and down. The lower end of the hook is equipped with a moisture-proof insulation rope. The insulate rope is wound and connected on the winch to realize the autonomous connection of the terminal.

![Figure 3. The entity structure model of the live working robot body.](image-url)

3.3. Operation Motion Planning of Live Working Robot
3.3.1. Up and Down Movement Planning of End Tools. When the robot is online and the end effector needs to be replaced, the lower end effector tool library is fixed with the insulated traction rope, and the robot lifting turntable rotates to lift the end effector tool library, as shown in figure 4. The lifting rotating disc rotates to raise the end effector tool library. The distance between the end effector and the bottom of the machine is judged by the upper camera. While continuously narrow the distance, use the adjustment string below the end effector tool library to adjust the fit between the end effector tool and the bottom surface. The bottom guide slope and the wire slope do not interfere and fit, the bottom guide slope and the lead slope do not interfere with each other. At this time, slow down the rotation speed of the lifting rotation disk for fine adjustment. When the guide cone pin is inserted into the pin hole at the bottom, slightly rotate the lifting rotation disk until the electromagnet is combined with the round cast iron. Touching the contact sensor, the lifting and rotation disk stops rotation, and the online step of the tool library is completed, so that the robot can realize the end self-reconfiguration on line.
3.3.2. Motion Planning of Robot Crossing Over Damper. When the live working robot travels along the wire, the camera on the robot body is responsible for the inspection of the wire, the damper and the equipment under the crimping tube, the camera on the robot arm is responsible for the inspection of the wire, the damper and the equipment above the crimping tube. When inspection small defects on the damper, the operator can operate the robot arm to allow the camera to reach into the gap for fine inspection. At the same time, through machine vision technology and visual servo control, the robot can autonomously locate the operating object to achieve online independent maintenance work. Figure 5 shows the simulation of robot crossing obstacles and wire damper inspection.

3.3.3. Motion Planning of Robot Line Fittings Inspection. When the live working robot travels along the wire to the wire clamp, the pinch wheel, brake and equipotential wheel are driven by the telescopic motor of the walking arm, the pinch wheel is overloaded and yields the compression spring, and the brake pad tightens the wire. The live working robot is parked on the line and the operator can operate the mechanical arm to allow the camera to reach near the fittings to carry out fine inspections of fittings such as hanging rings, hanging plates, bolts, split pins, spring pins and bowls. The simulation of robot fittings inspection is shown in figure 6.
3.3.4. Motion Planning of Robot Crossing Over Spacer. First, the robot goes online hoisted by a drone, and then the robot hangs the hook on the one-phase wire through the mechanical arm, and drives the robot body to cross the spacer bar through the sliding of the hook on the transmission line, and finally the robot two wheels go online to start the inspection operation. Figure 7 is the simulation of robot crossing obstacles spacer and inspection.

4. Development of Live Working Robot Prototype
Through the integrated design and manufacturing of mechanical systems, hardware measurement control systems, software systems and vision systems, a physical prototype system of a single-arm power working robot has been developed. The design and manufacture process of the robot body is shown in figure 8 and control commands are sent to the online robot through the ground base station. The robot can flexibly realize joint motions such as rotation and expansion of the single-arm robot. Compared with the traditional single-arm live working robot, the single-arm robot is more flexible in motion and has a wider working space at the end of the robot arm, especially the robot developed in this paper can realize the maintenance and fine inspection of small-sized and heterogeneous line fittings on the transmission line, and its inspection efficiency and live-line operation reliability can be greatly improved.
5. Conclusion and Prospect
This paper proposes a solution to assist the replacement of manual work by a single-arm live-work robot for power transmission line inspection and work tasks. The entity model of the single-arm live-work robot is designed, and physical motion planning and work simulation are carried out for typical work tasks. Finally, the physical prototype system of the robot was developed to verify the feasibility and effectiveness of the design in this paper. At the same time, there are many key technical issues in the practical process of single-arm powered work robots that need to be further studied, such as single-arm coordinated motion control, single-arm robust motion control in a disturbed environment, single-arm visual servo motion control And so on, these core technologies are the key to improving the automation level, intelligence and practicality of the entire charged robot operation system. These are the key and focus of follow-up research.

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