The Hot-line Work Robot for Power Distribution Network

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Abstract. Aiming to solve the problems of safety, low efficiency and large volume of existing distribution network robots, a new distributed live working robot based on the master-slave control algorithm with weak stiffness and large lag is designed in this paper. The smaller robot body is used in the multi-level three-dimensional insulation isolation and shielding measures of the robot which realize the quick replacement of the working end such as the general mechanical, control and electrical interfaces. In the control system, ARM microprocessor is the signal processing terminal, displacement sensor and force sensor are the intermediary of signal measurement and closed-loop feedback respectively, which realizes the remote operation of the operator.

1. Introduction
The Electric power industry is the foundation of the national economy, and the distribution network in the power system is the key to ensure the continuous supply of power, which plays a very important role in the whole power supply system. Once the line breaks down suddenly or the equipment defects are detected, the distribution network system is mostly radial topology, which can not guarantee the continuous operation by changing the operation mode. Distribution network live working has become the most direct and effective means in reducing distribution network power outage time and improving power supply reliability. In recent years, with the steady development of China's economy, higher requirements are put forward for the voltage quality, power supply capacity and power supply reliability of the power supply network [1]. In the world, research on distribution robot has been carried out for a long time. As one of the powerful robot industry countries, Japan began research on related technologies in the 1980s [2]. In China, the live working of distribution network is mainly the cutting and splicing of drainage pipes. The 6-10KV distribution line network is the infrastructure of power supply system which is characterized by dense equipment, complex lines, narrow space, small distance to the ground and low insulation level. Thus, it is easy to be affected by unstable factors such as atmosphere, rain, lightning and other external factors. What is more, the maintenance work is large and difficult. However, robot technology Application can effectively solve the above problems [3]. Aiming at the disconnection and wiring engineering of the live working robot in the distribution network, a crawler mobile robot is designed by studying the basic action elements of live working robot, which improves the adaptive control algorithm of the manipulator, and increases the adaptability of the live working robot in the distribution network to complex multi objects and narrow space. The task of live tapping is completed, the safety and efficiency of live working is improved, and the scope of work is widened by the analysis of distribution network live working robot with multi
manipulator insulation isolation. It is of great significance to develop the distribution network live working robot based on the weak rigidity and large time delay master-slave control algorithm. In this paper, a configuration of live working robot for distribution network based on the master-slave control algorithm with large delay and weak rigidity is proposed, which can be used to solve the problem of personnel safety, low efficiency, large size and the mobile mode.

2. Design and development of the whole mechanism of distribution network robot

2.1 Overall structural scheme of distribution network working robot

The overall structural scheme of the distribution network working robot is shown in Figure 1. The distribution network working robot is mainly composed of a mobile insulation platform, a robot body, a working arm, a control system, an operating system, a communication system, and a power supply system. The mobile insulated platform chassis adopts a crawler type, and four self-levelling legs which are arranged symmetrically on both sides are used as the levelling mechanism of the insulating platform. The upper end is connected with the hydraulic lifting arm, the telescopic arm through the 360° rotating platform, and the lifting arm and the telescopic arm during transportation. The arm can be folded to reduce the occupied space, the telescopic arm and the lifting arm move upward when working to raise the robot working body to reach the working position. The robot body is connected with the end of the telescopic arm of the mobile insulation platform which is driven by a motor, and the work task is completed through the cooperation of multiple work arms. The control system and power supply system are designed in the robot body to realize the operation control and continuous power supply of the robot, and the information communication between the robot and the ground operation system is realized by Wi-Fi communication.

![Figure 1 Overall structure scheme of robot](image)

1. Automatic balance of mobile insulation platform; 2. Robot body; 3. Base station of control; 4. End of operation ((1) End peeler (2)End clamp (3)Clamp installer at end)

2.2 Development of distribution network robot

The robot is composed of 3 mechanical arms with 6 degrees of freedom including cross slide, tool conveying device, body, vision system, communication module, motor driver, wire end, loading end, fastening installation end, etc. The multi-level three-dimensional insulation isolation and shielding measures of the robot are improved, the mechanical, control and electrical interfaces of the general quick replacement end are designed, which achieve the quick replacement of the operation end, as shown in Figure 2.
1. Robot control box; 2. Horizontally moving platform; 3. Manipulator for grabbing; 4. Ring tool conveyor; 5. Longitudinal moving platform; 6. Manipulator for installation of equipment clam; 7. Manipulator for peeling insulated conductor; 8. Adjustable focus vision sensor; 9. Wireless communication device

Figure 2 Structure composition of development robot

The robot control box moves along the mobile insulation platform through x-axis and y-axis cross slide (as shown in Figure 3), so as to ensure the effective space for cooperative operation of multiple manipulators. Insulated wire stripping device manipulator has 6 degrees of freedom, which can reach any position within the working point and can complete the insulation stripping task independently. The grab manipulator is mainly used in wire cleaning, coating conductive grease and installation of insulation protection cover.

1. Driving motor; 2. Screw nut mechanism; 3. Horizontally moving platform; 4. Longitudinal moving platform; 5. Guide seat

Figure 3 The composition of the X and Y axis slide mechanism

3. Technical difficulties and solutions of distribution network operation robot

(1) The working space of distribution network is narrow. There are many obstacles, and it is necessary to keep a safe distance all the time. At the same time, the induced voltage will also affect the operation in the strong electromagnetic field environment by the metal parts of the robot.

Solution: In order to avoid the robot's disoperation or refusal to move and prevent the interference or damage of the induced voltage to the electronic components of the robot, it is necessary to
overcome the multi-level three-dimensional insulation isolation technology of the robot and the robot shielding technology (as shown in Figure 4) [4].

![Figure 4 Research contents of robot insulation isolation and shielding technology](image)

(2) Although the robot has high rigidity and limited vision positioning accuracy, it is not easy to identify and grasp the weak rigidity wire. At the same time, the serious interference of electromagnetic clutter to the wireless communication signal will cause serious delay of the force control system, but it still requires the robot's action accuracy and real-time performance to meet the standards.

Solution: The relative positioning control method of each manipulator is studied to overcome the influence of the flexible swing of the lifting arm, improve the operation stability, and achieve precise control and stable operation. The delay analysis and algorithm in wireless network control system are studied to improve the accuracy and dynamic response of force telepresence function, and capture the force situation when the remote slave manipulator interacts with the environment truthfully and accurately. (as shown in Figure 5)
(3) Due to the limited working space of the robot, the three manipulators are easy to collide with each other and the wires. Thus, it is necessary to design the working end which is easy to carry, high efficiency, uniform interface, easy to replace and flexible to adjust the spatial position and attitude in deal with many working procedures and different objects.

Solution: the trajectory planning of the robot is studied and the kinematic models of its mobile insulation platform including lifting mechanism and mechanical arm is established. Then, the structure is optimized by simulation analysis in this paper. At the same time, it calculates the corresponding joint torque, acceleration and speed of the mechanical arm, the position accuracy of each arm, and realizes the coordinated control and cooperative operation of multiple mechanical arms. The interface technology of mechanical and electrical control is conquered according to the work flow of robot. A light, flexible and replaceable mechanical claw is designed to handle the quick replacement and improve the work efficiency.
The kinematics model of the manipulator the spatial coordinate system are established. The solution is completed under the relevant constraints [5]. The free space and obstacle space are described completely by the grid division of the whole working space. The optimal collision free path is planned according to the safe distance between the cable and the nearby cable as shown in Figure 6. The spatial working range of the robot is obtained by calculating the first three axes of the robot. The spatial motion chain which is composed of motion pairs connecting each member is used to simulate the serial robot. The D-H parameter method is used to solve the forward kinematics of the robot by describing the relative positional relationship between the rods.

(4) The terrain of live working in distribution network is complex, so it is necessary for the robot to overcome different obstacles in walking process, at the same time, it needs to ensure the level of mobile insulation platform is stable.

Solution: The robot automatic balance model is established by the torque method. The objective function of the stability coefficient is obtained. The stability of the whole machine and the reaction force of the legs are analysed and the relationship is revealed for improving the stability of the robot. The main sensor of the system selects the dual-axis tilt sensor. The sensor has a detection function on the two-axis axis for levelling the real-time angle detection of the chassis. The processor compares the detected angle with the levelling accuracy and obtains the difference. Then, the difference signal is amplified and output to the corresponding electromagnetic reversing valve, and the corresponding leg moves until it is levelled, as shown in Figure 7.

![Figure 7 Installation diagram of the dual-axis tilt sensor](image)

(5) Master-slave control system: The control system of master-slave remote control manipulator is composed of active system and driven system. The active system includes the main operating manipulator and its driving device. The driven system includes the slave operating manipulator and its control driving device. The main hand and the slave hand have corresponding motion range and the same number of motion joints respectively. The operator operates the master hand to generate the position, then the slave hand follows the master hand to complete the remote control task. The master-slave control system greatly enhances the operator's perception of the environment, allowing the operator to get a real sense of on-site work and improving their efficiency and reduce work time [6]. The robot proposed in this paper has good real-time performance and the ability to sense its own motion state information, so that it can drive the actuator to achieve real-time precise control. The overall control system scheme is designed by the motion control requirements of the working manipulator. As shown Figure 8. The control system uses ARM microprocessor as signal processing terminal. The displacement sensor and force sensor are used as the medium of signal measurement and closed-loop feedback. The main functional modules include: main controller, slave controller, robot position detection, communication and power supply, and drive signal conversion. The improvement of the performance of the master-slave remote operating system is often limited by various factors,
such as the construction and accuracy of the force sensor, the acquisition, processing and transmission of the force signal, the drive and control of the main motor torque motor, etc. The delay of the force feedback signal is one of the most critical factors.

Solution: The main purpose is to use the master-slave control system force feedback signal delay prediction algorithm.

(6) Due to the poor rigidity of the cable, there will even be shaking when the wind is strong. At the same time, the operation height of the robot operating assembly line is also very high. Therefore, when the tool end of the robot is connected with the cable, there will inevitably be a certain position deviation and attitude deviation between the two docking bodies.

Solution: There is a certain tolerance capability in the docking mechanism. The end-executing tool is used to assist the capture in order to capture the target. In the specific operation process, the flexible control strategy should be used to complete the fixation (flexible capture) of the weak rigid cable, stripping (flexible stripping for the cable) of the cable, and the removal and installation of the clamp (flexible coordination for the exposed wire). Sliding mode control is adopted to resist the influence of uncertain factors such as external interference and parameter perturbation. As shown in Figure 9.

Figure 8 Master-slave control system

Figure 9 Control block diagram of compliant grip system
4. Summary
Aiming at a series of problems existing in the current distribution network operation robot such as personnel safety, low efficiency and large volume, a distribution network robot is designed by weak rigidity and large time delay master-slave control algorithm which achieve the key technology breakthrough and action planning of the robot. The kinematic modelling and simulation are used to analyse the stripping process of the robot. The results show that the master-slave control algorithm based on weak rigidity and large time delay is effective, which provides a foundation for the subsequent upgrade of distribution network operation robot.

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