Design of Quadruped Inspection Robot for Substation

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Abstract. The intelligent inspection robots in substations mostly use wheeled chassis, which have good passability when running on flat roads, but it is difficult to effectively cross obstacles under terrain conditions such as steps and stairs. A quadruped inspection robot for substation is designed to improve the walking ability of the robot with a four-leg alternate walking mode to optimize the leg structure design for road conditions such as steps and stairs in the substation. The robot is equipped with pan-tilt detection components and inspection equipment such as multi-degree-of-freedom manipulators can complete intelligent inspection and lightweight maintenance tasks in open substations, and achieve full coverage of the inspection area.

1. Introduction
At present, Substation inspection robots mainly use wheeled chassis and crawler-type chassis. They are suitable for running on relatively flat and gravel roads. However, they cannot effectively cross steps and stairs. The substation inspection robot cannot timely remove the hidden trouble in the light maintenance tasks such as the removal of foreign objects on the road in the process of inspection. The existing foot-type robot platform is a universal platform. Its legs adopt a rigid structure. There is only one degree of freedom in the thigh and calf, and the leg structure is simple.

Quadruped robots are mostly oriented to scientific research and education. The Spot robot of Boston Dynamics can complete tasks such as walking on flat and gravel roads and climbing steps. The ANYmal robot of the Swiss Federal Institute of Technology Zurich is equipped with a pan-tilt and a camera, and realizes the function of climbing stairs in a static gait. Quadruped robots are oriented to the scientific research and education markets in China, and have not yet been industrialized. For the automatic inspection scene in the substation, the function of stepping over steps and climbing stairs is lacking. Based on the needs of inspection and lightweight maintenance in substations, a quadruped inspection robot for substations is designed to complete intelligent inspection and lightweight maintenance tasks in open substations, and achieve full coverage of the inspection area.

2. Mechanical Design of Robot
The quadruped inspection robot for substation is mainly composed of a quadruped mobile platform, a PTZ(Pan/Tilt/Zoom) detection component, a multi-degree-of-freedom manipulator and a control system, as shown in Figure 1. The quadruped mobile platform is the mobile mechanism of the robot, which provides support for the PTZ detection components and the multi-degree-of-freedom manipulator. The quadruped mobile platform has discrete foot points and has better terrain passability.
The quadruped platform has stronger stability than double feet and simpler structure than hexapods. The single leg has 3 degrees of freedom. The calf can be rotated and adjusted according to the different working conditions of the upper and lower steps, avoiding the walking interference of the single structure on the step boss, and improving the passage of obstacles. The PTZ detection component is mainly composed of a visible light camera and an infrared camera. It has two degrees of freedom, pitch and rotation, and can complete the observation of the equipment in the substation; the PTZ detection component can be replaced with a multi-degree-of-freedom robotic arm, with a visible camera at the end of the robotic arm and the work tool interface which includes mechanical structure and electrical interface. The visible camera realizes the precise positioning of the robot arm. The robot arm is equipped with different work tools to complete the light-weight maintenance tasks such as electrical cabinet switching and foreign objects removal.

The PTZ detection component has the same connection method as the multi-degree-of-freedom mechanical arm, and the electrical interface is a quick-change interface, which can be quickly replaced. The control system is located in the abdomen of the quadruped mobile platform to control the robot's walking gait planning and the inspection tasks of the PTZ detection components.

The quadruped mobile platform is mainly composed of the rotating legs, the antennas, a laser sensors and a depth camera. The rotating leg has 3 degrees of freedom, and has the functions of walking and leg rotation. The antenna can realize the data transmission and communication between the robot's control system and the remote control terminal. The laser sensor and the depth camera can capture the road conditions during the robot travel and perform 3D modeling of road conditions. The control system performs robot gait planning based on the road condition information to complete the action of walking or crossing obstacles.
position and posture. The walking drive motor will be in working condition for a long time. The walking drive motor is a high-torque DC motor, and a cooling fan is used during walking to force heat dissipation. The thigh and the calf are connected by a rotating joint, and the leg rotating motor is built in, as shown in Figure 3. After the leg is raised, the leg rotating motor is driven, and the calf can rotate around the thigh axis.

![Fig.3 The main components of rotating leg](image)

9. The walking drive motor, 10. The thigh, 11. The rotary joint, 12. The calf, 13. The foot, 14. The cooling fan

The calf adopts a curved design, combined with a rotating joint, which can avoid interference and collision between the calf and the edge of the step when the calf is going up and down the steps, thereby preventing the robot's center of gravity from instability due to external force impact. The joint between the calf and the foot is equipped with a shock-absorbing spring to avoid rigid impact between the leg and the ground, as shown in Figure 5.

![Fig.5 The shock-absorbing spring](image)

The different postures of the robot’s leg mechanism are shown in Figure 6.
3. The Control System of Robot

The hardware design of the quadruped inspection robot is the electrical connection between the quadruped mobile platform and the PTZ detection components, multi-degree-of-freedom manipulators, and communication equipment. The equipment carried by the four-foot mobile platform mainly includes: the PTZ detection component, the visible light camera, the infrared camera, a wireless bridge and switch, etc. The overall structure design of the hardware of the quadruped inspection robot’s control system is shown in Figure 7.

The quadruped mobile platform provides 80V power supply, and the 24V, 12V and 5V power supply are obtained through the power conversion module from 80V to 24V, 24V to 12V, and 12V to 5V. The supply power is used for the pan-head, visible light camera, infrared camera, switch and other equipment. The electrical interface of the wireless network bridge is POE interface, and the POE transfer module is used for power supply and communication.

The visible light camera and the infrared camera are network communication, which is connected to the switch through the built-in communication cable of the PTZ, the four-foot mobile platform opens the network port and connects to the switch, and the wireless bridge is connected to the switch through the POE module to realize the network communication of the entire system. Since the PTZ detection component is controlled by the 485 bus, the USB to 485 module is used to communicate. The multi-degree-of-freedom manipulator is connected to the switch through a network cable, and remotely controlled by reading the IP.

The overall structure design of the Software of the quadruped inspection robot’s control system is shown in Figure 8.
The quadruped inspection robot adopts the ROS robot control system as the control and communication framework, and realizes the data communication between the master computer and the slave computer through the ROS interface program. The slave computer control of the robot includes navigation and positioning, quadruped mobile platform control (gait planning, legs control, stabilization control), PTZ inspection and multi-degree-of-freedom manipulator control. The master computer control is mainly the background analysis of inspection data.

4. Inspection Method
When the quadruped inspection robot carries out inspection tasks in the substation, it adjusts the direction of the legs according to the obstacles on the spot. Remotely control the robot to reach the designated position, adjust the robot's posture, and use the PTZ detection components to perform detection tasks on the corresponding substation equipment. When the robot walks along the set inspection route, it collects surrounding environment information during the inspection process, and then identifies the type of electrical equipment to be inspected and the characteristics of the current running road surface. The robot can extract the semantic information of the electrical equipment to be inspected, and obtain information related to the electrical equipment and monitoring point information to be inspected, according to the relative position relationship between the robot and the detection point and the current running road characteristics. Local path planning is used to control the robot to depart from the set inspection route and go to the best observation position of the equipment to conduct inspection data collection. When maintenance is required, the multi-degree-of-freedom manipulator is installed to adjust the robot's posture and perform maintenance tasks.

5. Conclusions
The quadruped inspection robot for substation uses a quadruped mobile platform as the walking mechanism. The legs can be rotated and switched according to the obstacles on the road, and can walk freely in the equipment area such as stones and steps. The robot is equipped with PTZ detection components to patrol the power equipment in substation, and send the detection data to the inspection system for big data analysis. The robot can be equipped with a multi-degree-of-freedom mechanical arm. The mechanical arm and the PTZ detection component adopt a unified mechanical and electrical interface, which can realize rapid replacement, and complete the lightweight maintenance task by remotely controlling the mechanical arm.

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