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Design and Research of Intelligent Bypass Cable Laying Robot

Lu Guowei, Liu Yan, Zhang Wei, Zhao Jinfeng, Li Jiao, Wang Zhi, Wang Maolin, Li Xiangfei, Yao Longwei, Zhang Zefeng, Zhao Xue, Jiao Jiao*

Shanxi Jinyuan Electric Chemical Cleaning Center Co., Ltd., Live Working Center, Taiyuan, 030006, China

*Corresponding author

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Abstract: To address the low construction efficiency of traditional cable laying devices in complex environments, this study develops an intelligent bypass cable laying robot. Integrating terrain adaptation components and cable lubrication components, the robot achieves intelligent control through cameras and an external controller. It can adapt to diverse road conditions, automatically clear obstacles, and realize cable lubrication and guidance, thereby significantly improving the efficiency and reliability of cable laying. This paper systematically elaborates on the robot's structural design, working principles, and experimental verification results, providing an innovative solution for the intelligent development of cable laying technology.

1. Introduction

In modern power systems, the stable and efficient laying of bypass cables serves as a cornerstone for ensuring uninterrupted power supply, especially in urban power grids where load density is high and power outage risks are strictly controlled [1-3]. With the rapid advancement of urbanization and the continuous expansion of power infrastructure, the operating environment for cable laying has evolved into a complex mosaic of challenges—uneven road surfaces, scattered construction debris, sudden elevation changes, and dense obstacles such as scaffolding and temporary material stacks have become commonplace [4]. These unstructured conditions not only hinder the maneuverability of traditional laying equipment but also lead to frequent interruptions in the construction process. For instance, manual intervention is often required to clear obstacles or adjust the equipment's path, resulting in prolonged construction cycles, increased labor costs, and even potential safety hazards in high-risk areas. As society's demand for reliable power supply grows increasingly stringent, the inefficiency and unreliability of conventional cable laying methods in complex environments have become a critical bottleneck restricting the development of power construction. Thus, there is an urgent need for innovative technical solutions that can adapt to diverse terrains and automate obstacle handling, making the development of intelligent cable laying systems an imperative task with significant practical value.

Against the backdrop of accelerating the construction of new power systems, traditional manual cable laying faces additional challenges such as high risks in high-altitude operations and low efficiency in complex terrain. Intelligent robots, as an emerging technological means, are gradually becoming a research hotspot in the field of power construction. In recent years, with the iterative upgrading of robot technology, enterprises such as State Grid have introduced cable laying robots in some pilot projects. Through automated traction devices and path planning algorithms, these robots have improved cable laying efficiency by approximately 30% [5]. However, current technologies still have significant limitations: most existing robots are designed for flat ground conditions, and their tracked or wheeled chassis struggle to achieve adaptive attitude adjustment on complex terrains such as mountains and wetlands. When encountering common obstacles at construction sites (e.g., scaffolding and temporary material stacks), robots lack autonomous perception and dynamic obstacle avoidance capabilities, relying only on preset programs for simple detours. According to industry statistics, the failure rate of existing cable laying robots in unstructured construction environments is 42% higher than in ideal working conditions [6], indicating that technological breakthroughs in adapting to complex surfaces and intelligent obstacle handling remain key bottlenecks for the large-scale application of robots in power construction.

To address the aforementioned limitations, this study proposes an intelligent bypass cable laying robot that integrates terrain adaptation, autonomous obstacle clearance, and cable lubrication guidance into a unified system. By leveraging real-time environmental perception through cameras and intelligent control algorithms, the robot is designed to dynamically adjust its posture in response to terrain changes, automatically clear small to medium-sized obstacles, and reduce cable friction through targeted lubrication. This paper will systematically elaborate on the robot's mechanical structure, working principles, and experimental validation, aiming to provide a feasible technical path for breaking through the efficiency and reliability constraints of traditional cable laying in complex environments, and thus contributing to the intelligent upgrading of power construction technologies.

2. Structural Design of Intelligent Bypass Cable Laying Robot

2.1 Overall Structure

As shown in Figure 1, the intelligent bypass cable laying robot mainly consists of an operation board, road surface adaptation components, and lubrication wire components. The operation board serves as the main structure of the robot, used for installing and supporting other components; The road adaptation component is installed on the bottom of the operation board to achieve stable walking and obstacle removal of the robot on different road surfaces; The lubrication wire component is installed on the top surface of the operation board to lubricate and guide the cables, improving the efficiency and quality of cable laying.

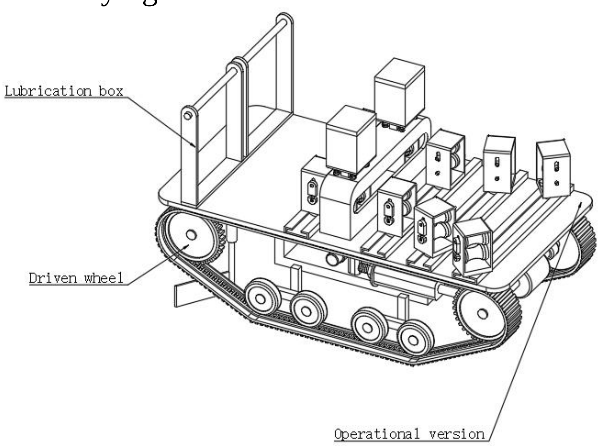

Figure 1 Intelligent bypass cable laying robot

2.2 Road Surface Adaptation Components

As shown in Figure 2,the road adaptation components include installation frame, drive platform, drive motor, gearbox, drive shaft, drive wheel, adjustment blind pipe, adjustment screw, tension spring, tension nut, limit plate, hydraulic rod, driven sleeve, driven shaft, driven wheel, walking track, camera, rotary motor, electric push rod, inclined plate, support wheel and pulley.

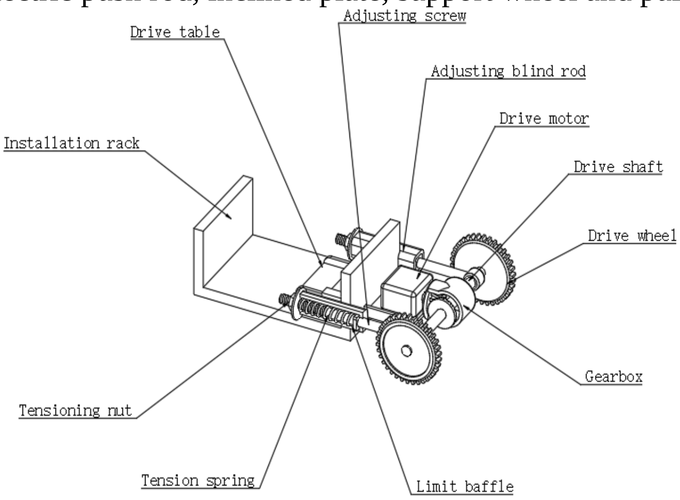

Figure 2 Internal components of road surface adaptation

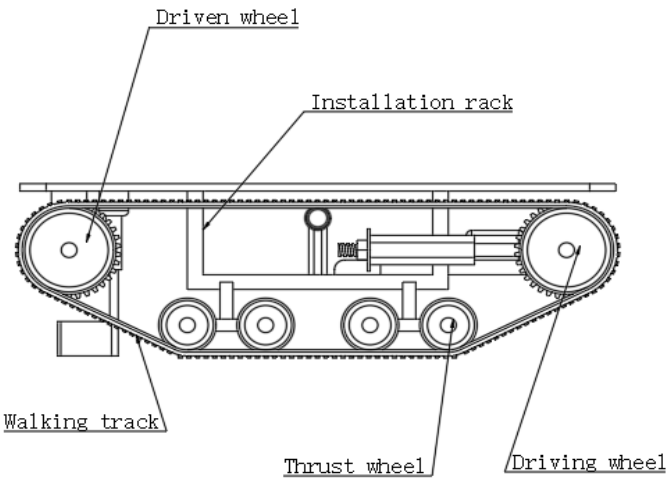

Figure 3 Road surface adaptation components

As shown in Figure 3,the installation bracket is welded to the middle of the bottom surface of the operation board, used for installing the drive platform and other components; The drive platform is installed through the sliding installation at one end of the mounting bracket, and the drive motor is installed at one end of the drive platform. Its output shaft is connected to the input end of the gearbox, and the output end of the gearbox is installed through the drive shaft. Drive wheels are installed at both ends of the drive shaft; The adjustment blind tube is symmetrically welded to one end of the installation frame near the drive motor, and the adjustment screw is installed inside the adjustment blind tube. One end is fitted with the drive shaft, and the outer side is fitted with a tension spring at the inside of the adjustment blind tube. One end is fitted with a tension nut through threads, and the other end is fixed with a limit plate; The hydraulic rod is symmetrically installed in the middle of the bottom surface near one end of the installation frame on the operating plate, and its extended ends are connected to both ends of the driven sleeve. The driven sleeve rotates and is connected to both ends of the driven shaft, and both ends of the driven shaft are equipped with driven wheels. A walking track is installed between the driving wheel and the driven wheel; The camera is installed between the hydraulic rods at the bottom of the control panel to monitor road conditions; The rotating motor is symmetrically installed on the operating board near the mounting bracket, and its output shaft is connected to the electric push rod. The bottom end of the extended end of the electric push rod is fixedly connected to the inclined baffle; The supporting wheel is symmetrically installed at the bottom of the installation frame, and the supporting pulley is installed in the middle of the installation frame, both of which are in contact with the inner side of the walking track, used to support and guide the walking track.

2.3 Lubricating Wire Components

As shown in Figure 4,5,the lubrication wire assembly includes lubrication box, threading hole, lubrication frame, fixed lubrication roller, movable lubrication roller, lubrication groove, feeding tube, storage box, support spring, pay off rack, guide rail, slider, guide frame, fixed guide roller, movable guide roller, bottom block, top block, rotating screw, rotating block, positioning screw and end cover.

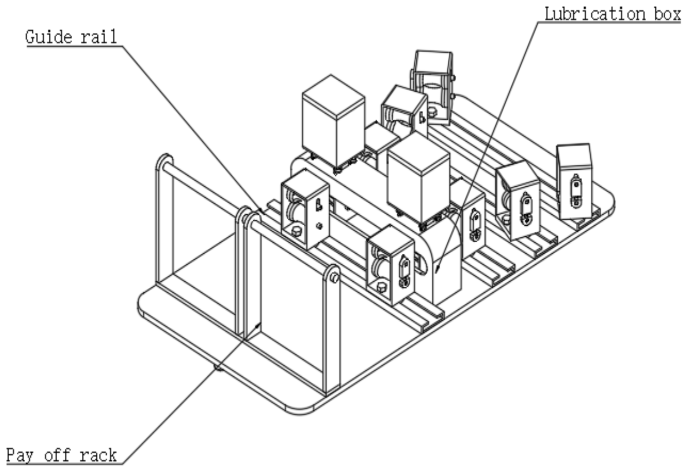

Figure 4 Lubrication wire assembly

The lubrication box is installed in the middle of the top surface of the operation board, with a threading hole in the middle. A symmetrical lubrication frame is installed inside, and a fixed lubrication roller is installed by rotating the bottom end of the lubrication frame. A movable lubrication roller is installed by sliding inside, and lubrication grooves are uniformly opened on the outside of both; The feeding tube moves through the lubrication box and lubrication frame in sequence, with a storage box installed at the top and a support spring welded at the four corners of the storage box bottom. The bottom end overlaps with the top surface of the lubrication box, and the top end is clamped and installed with an end cover; The pay off rack is installed at one end of the top surface of the operation board for installing cable coils; The guide rail is installed on both sides of the lubrication box of the operation board, and the sliding block is symmetrically installed inside. Its bottom end is fixedly connected to the guide frame; The inner bottom of the guide frame is rotated and fixed with a guide roller, while the inner top is slid and installed with a movable guide roller. One end of the fixed guide roller passes through the guide frame and is connected to the bottom block.

The movable guide roller passes through the guide frame and is connected to one end of the top block. The top surface of the bottom block is connected to a rotating screw, and the bottom end is welded with a rotating block. The top end is connected to the top block through a screw hole, and a positioning screw is installed through the screw hole at the inner bottom of the guide frame.

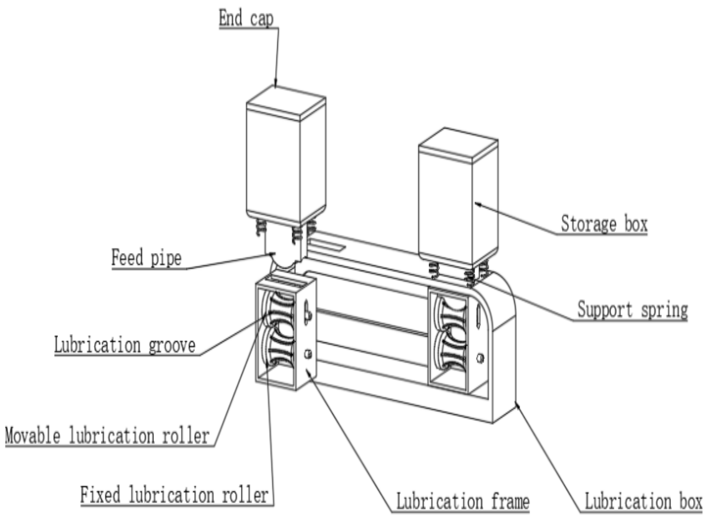

Figure 5 Schematic diagram of lubrication box

3. The Working Principle of the Intelligent Bypass Cable Laying Robot

3.1 The Principle of Pavement Adaptation

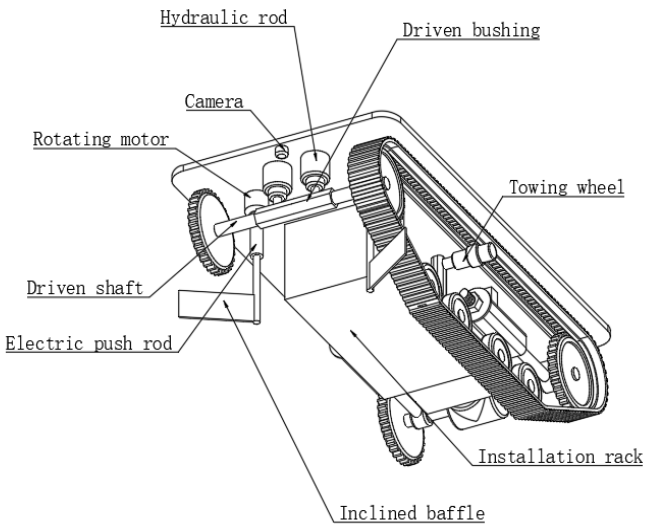

Figure 6 Bottom of pavement adaptation component

As shown in Figure 6, the robot monitors the road condition in real time by the camera: when encountering the uphill surface, the hydraulic rod pulls the driven casing and the driven shaft to move up, drives the driven wheel to move up, makes one end of the walking track tilt, increases the support area with the uphill surface, improves the stability of the uphill slope; When going downhill or in the plane driving, the hydraulic rod pulls the driven casing and the driven shaft to move downward, makes one end of the walking track fit the ground, expands the supporting area, and through the differential treatment of different road surfaces, always keeps the travel stable.

If there is the situation that the walking track is loose and can not advance, rotate the tension nut to pull the adjusting screw, the tension spring deformation changes the position of the drive wheel, and the drive motor moves synchronously, and the drive table translates and slides along the position of the mounting frame penetration, and the walking track is tensioned while ensuring the driving stability, and the track looseness affects the advance in the adjustment process.

When obstacles such as stones appear on the road of travel, the rotating motor drives the electric push rod and the oblique baffle plate to rotate, and the electric push rod promotes the oblique baffle plate to move down, makes it be positioned in front of the walking track of the march, along with the device advances, the stone slides to the middle position just below the operation plate along the inclined baffle plate, does not need to turn to avoid the smaller obstacle, also does not need to stop the device to carry out manual cleaning, further improves the continuity and high efficiency of cable laying.

3.2 Lubrication Wire Principle

As shown in Figure 7, 8, pull the cable sequentially through the guide box of one side of the lubrication box, the guide box of the lubrication box and the other side, facilitate the operator to lay the cable to the designated position on the ground, prevent the damage caused by the excessive bending angle in the cable laying pulling process or the scratch of the outer insulating layer, improve the convenience of laying.

Talcum powder is poured into the storage box, talc powder will enter the lubrication groove, with the cable continues to pull, talcum powder is smeared on the outside of the cable, in the process of the cable being continuously pulled out from the threading hole, it is continuously smeared on the surface of the cable, the loss of the outer insulation layer of the cable and the outside friction is reduced, the pulling resistance is reduced, the operator is convenient to pull the cable and change its position, and the convenience of cable laying is further improved.

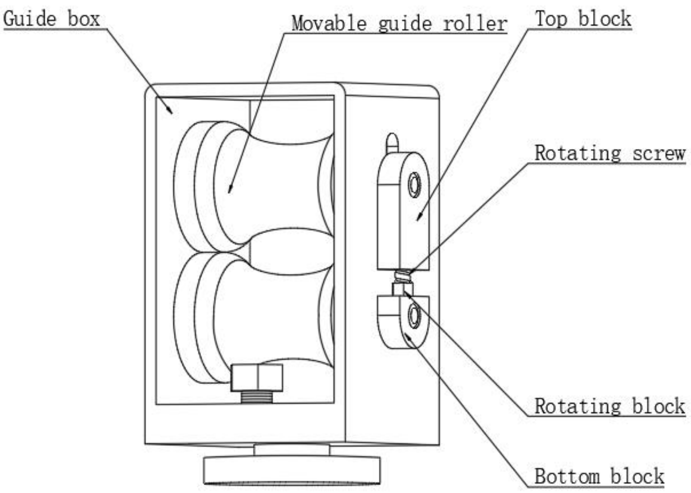

Figure 7 Guide box

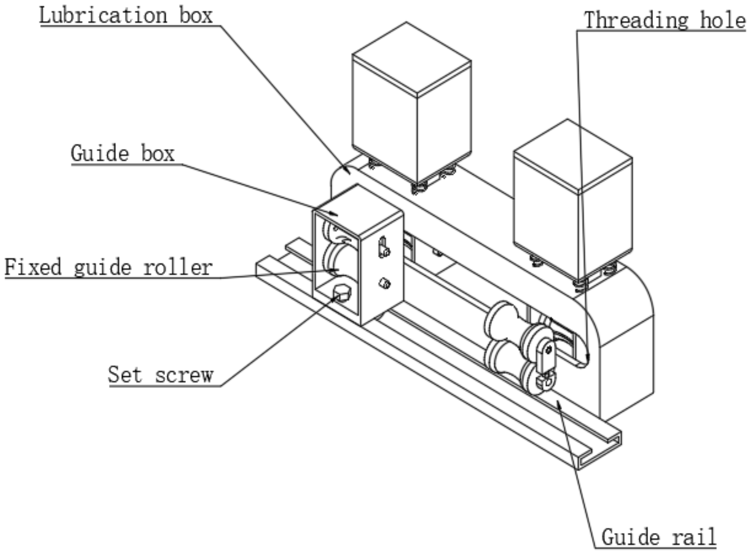

Figure 8 Wiring device

3.3 intelligent Control Principle

Camera input terminal and external controller output terminal electrical connection, drive motor, hydraulic rod, rotary motor and electric push rod input terminal with external controller output terminal electrical connection respectively, external controller input terminal and external power output terminal electrical connection. The camera transmits the road condition information that the camera shoots to the external controller, and the external controller controls the action of hydraulic rod, rotating motor and electric push rod according to the road condition information, realizes the automatic adaptation of robot to different road surface conditions and the automatic elimination of obstacles. At the same time, the external controller controls the speed and steering of the drive motor, and realizes the actions such as forward, backward and steering of the robot.

4. Experimental Verification

4.1 Experimental Apparatus and Methods

In order to verify the performance of the intelligent bypass cable laying robot, an experimental platform is built, including a test site and a cable laying experimental device that simulate different road surface conditions. The test site includes uphill roads, downhill roads, and roads with obstacles such as stones; The cable laying experimental device includes a cable coil, a pay-off frame and a measuring instrument.

The experimental method is as follows: the robot is placed at the starting point of the test site, the robot is started, and the walking speed, stability and obstacle removal effect of the robot under different road surface conditions are recorded; In the cable laying experiment, the cable coil is installed on the pay-off frame, the robot is started, the cable is pulled for laying, and the cable laying speed, lubrication effect and insulation layer wear are recorded. Repeat the experiment multiple times and use the average value as the experimental result.

4.2 Experimental Results and Analysis

The test results of road adaptability show that the robot can walk stably on both uphill and downhill roads at 15 °, with a walking speed of 0.5m/s, and the walking track does not slip. On the road surface containing obstacles such as stones, the success rate of the robot to automatically remove obstacles is more than 95%. The experimental results of cable laying show that the cable laying speed of the robot is up to 1.2m/min, the cable lubrication effect is good, the wear rate of the insulation layer is reduced by more than 40%, and the cable bending angle is controlled within a reasonable range, and there is no cable damage.

5. Conclusion and Prospect

The intelligent bypass cable laying robot designed in this study integrates the pavement adaptation assembly and the lubrication wire assembly, realizes intelligent control through the camera and the external controller, can adapt to different road conditions, automatically remove obstacles, and lubricate and guide the cable, which significantly improves the efficiency and reliability of cable laying. Experimental verification shows that the robot can walk stably under different road conditions, has a high success rate of obstacle removal, fast cable laying speed, good lubrication effect, and low insulation wear rate.

Future research work can be carried out from the following aspects: Further refine the robotic structural design to enhance load capacity and endurance. Integrate advanced sensor technologies and intelligent control algorithms to strengthen the robot's autonomous decision-making capabilities and environmental adaptability. Conduct research on robotic applications in complex terrains and harsh environments to expand operational scope. Explore collaborative operation technologies between robots and other construction equipment to improve the overall efficiency of power grid construction.

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References

*[1] Li Y, Jiang L, **e M, et al. Advancements and challenges in power cable laying[J]. Energies, 2024, 17(12): 2905.*
[2] Taormina B, Bald J, Want A, et al. A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions[J]. Renewable and Sustainable Energy Reviews, 2018, 96: 380-391.
[3] Yang X, Liu J, Lv N, et al. A review of cable layout design and assembly simulation in virtual environments[J]. Virtual Reality & Intelligent Hardware, 2019, 1(6): 543-557.
[4] Song Z, Ning K, Wang M. Shortest Path Planning Method for Cable Laying Based on Improved Particle Swarm Optimization Algorithm[C]//ECITech 2022; The 2022 International Conference on Electrical, Control and Information Technology. VDE, 2022: 1-6.
[5] Boschetti G, Carbone G, Passarini C. Cable failure operation strategy for a rehabilitation cable-driven robot[J]. Robotics, 2019, 8(1): 17.
[6] Raman A, Walker I, Krovi V, et al. Cable failure tolerant control and planning in a planar reconfigurable cable driven parallel robot[J]. Frontiers in Robotics and AI, 2023, 10: 1070627.