Research and application of substation cable trench inspection robot communication system

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Abstract: The substation cable trench inspection robot is mainly used to inspect the high-voltage cables in the underground cable trench of the substation, so as to find various hidden dangers in time. However, due to serious electromagnetic interference in the cable trench and no communication network underground, the environment is more complicated. Aiming at the complex environment in the cable trench, this paper designs a WLAN-based cable trench inspection robot communication program, combining WLAN with directional antennas, and relaying through relay routing, so that the communication between the robot and the PC is divided into pipeline communication and ground communication. Two parts. At the same time, the communication hardware, software, and protocol are designed based on the B/S architecture, which effectively improves the communication distance. Through field verification, the packet loss rate of the communication system proposed in the thesis is less than 0.5‰, the communication is stable, and the communication task of the robot in the cable trench of the substation can be completed well.

1. Introduction
Cable trench is mainly used for laying and replacing the underground pipeline of telecommunications cables or power facilities, and can also be used as the protective structure of the laid cable facilities. Its structural form is round, rectangular, arch, etc. Although the substation cable trench has the advantages of cable laying specification and better pipe straightness compared with other cable trenches, it still has the disadvantages of bad environment, narrow space and difficult daily trench inspection. In order to reduce the work burden and risk of workers operating in the cable trench environment, a mobile robot with various monitoring sensors -- cable trench inspection robot is designed to serve the cable trench inspection task. At present, the structural control design of inspection robots is relatively mature. However, due to the characteristics of strong electromagnetic interference in substation cable trench, strong signal shielding of underground pipeline wall, and large transmission amount of images and videos, traditional communication methods such as LoRa cannot well meet the communication needs.

At home and abroad, there is no separate research on cable trench inspection robot communication, but the inspection robot belongs to the pipeline robot, and there are many researches on the communication system of the pipeline robot at home and abroad. For the pipeline robots with different functions in different pipelines, the system needs to be designed separately [1-3]. For the inspection robot in cable trench, the system design that meets the inspection task is also carried out [4]. Compared
with the ground robot, the positioning and communication of the robot in the pipeline will be more fuzzy. Therefore, relevant scholars have designed the communication and positioning of the robot in a special way to meet the functional requirements of the robot [5-6].

The application of cable trench inspection robot can take the place of personnel to enter the cable trench for abnormal detection, effectively reduce the number of construction, improve the inspection level of cable line, and play a vital role in the intelligent inspection of cable trench. In order to solve the cable trench inspection robot is not suitable for wired communication, but to ensure high communication real-time problem, the cable trench robot wireless communication system for the overall design, WLAN combined with directional antenna, greatly improve the communication distance, has the advantages of simple and flexible control, stability, good security and so on.

2. Working principle of cable trench inspection robot
Cable trench inspection robot consists of ground control console, wireless control system and inspection robot, as shown in figure 1. The industrial computer is arranged on the inspection robot, and is equipped with a directional antenna, so that it sends directional signals to the tail direction for the relay router to receive.

![Figure 1. Schematic diagram of cable trench inspection robot.](image)

- Remote console
- Gateway device
- The router
- Safety wire
- The CCD camera
- Inspection robot
- Industrial computer and directional antenna

When the cable trench inspection robot works, the console first issues the order task, and the idle inspection robot is dispatched to carry out the inspection task from the specified position. The whole inspection process is controlled wirelessly by the remote control system on the ground, and the indexes of the robot and the video images transmitted by the camera are received.

3. Communication strategy and implementation of cable trench inspection robot

3.1. Design of inspection robot communication system
The communication system structure of cable trench inspection robot designed in this scheme is mainly composed of three parts, namely underground communication, ground communication and data processing communication. The wireless communication is ensured in real time by means of measures separating the underground communication from the ground communication. The communication system is shown in figure 2.

The underground communication is composed of inspection robot, industrial computer and underground relay router. Signals transmitted underground include video signals, control signals and detection signals. The related detection equipment and video equipment are connected to the industrial computer on the vehicle through the serial port, which are used for the control of the cable trench inspection robot, the sending and receiving of sensor signals and the uploading of videos. Due to the large amount of video signal transmission, which requires high stability and real-time performance, the video is transmitted by mature products alone. When the industrial computer receives the sensor signal,
it will transmit it to the underground relay router through the directional antenna. It will also receive the control instructions from the relay router to complete the whole underground communication.

Ground communication wireless data receiving layer by using wireless network base station 5g wireless communication network, the use of ground gateway equipment for protocol conversion, complete the data transmission of packets underground reseal after parsing, finally through the wireless network for data transmission, until the data processing center receives the transmitted data, complete the whole ground wireless communications.

The communication between data processing mainly uses TCP/IP protocol to parse the received data packets. In order to access and download the data and information of cable trench inspection in real time, the analyzed data will be automatically uploaded to the database server in the background, so as to ensure the real-time monitoring and control of the whole period and process of cable trench inspection.

3.2. Design of inspection robot communication hardware
The hardware circuit of cable trench inspection robot communication system is mainly composed of inspection robot, CCD camera, console, coordinator, wireless network transceiver module and power supply module. See figure 3.

The controller will generate a variety of control commands, such as forward, backward, turning of the inspection robot, lift and drop of the cradle head, etc. The coordinator is connected with the controller and placed in the inspection vehicle. Its responsibility is to receive the response signal and send the corresponding control instructions. The coordinator and controller constitute the main control part of the robot. The industrial computer is placed on the control board of the inspection vehicle. When the
industrial computer receives the robot control instruction, it will forward it to the main controller, so that the inspection robot can perform corresponding actions. The main control part will also send back the wireless response signal after executing the corresponding action. Due to the harsh environment in the cable channel, serious electromagnetic interference, and obvious shielding effect of the channel wall to the signal, the traditional LoRa communication method cannot play a good communication effect, so the way of setting relay router in the pipeline can achieve stable wireless signal transmission in the channel. The wireless communication structure of signals between hardware of the system is shown in figure 4.

![Diagram](image.png)

Figure 4. Wireless communication structure diagram.

3.3. Design of inspection robot communication software

In this section, the ground console of inspection robot is designed using web visual interface based on MQTT protocol, which is composed of buttons to control the running of the car, monitoring interface for the running state of the car, monitoring interface for the surrounding environment of sensor detection and video monitoring interface. The keys include the stepper motor's forward (reverse) turn control keys, the robot's left (right) turn action control keys, the motor stop control keys, the cradle head's lift (drop) action control keys, and the camera's start and close buttons. Vehicle monitoring consists of the current cover plate, vehicle electric quantity, inspection mileage and vehicle attitude. Environmental monitoring consists of temperature, humidity, Co concentration and smoke concentration. See figure 5.

![Image](image.png)

Figure 5. Initial interface of cable trench intelligent inspection visualization platform.
3.4. Design of inspection robot communication protocol

The video information transmission of the camera is a mature product, which will be automatically compressed into digital video and sent out through the wireless network. After receiving the video signal, the upper computer will decode it through the video server and show it in real time. In this paper, the communication protocol design of inspection robot consists of only two parts, which are control signal communication protocol and sensor signal communication protocol. The control signal communication protocol is mainly to contract and standardize the output signal of the Web control end, so that the vehicle can execute the correct action instruction. Sensor signal communication protocol is the convention and specification for the collected signals to be sent to the coordinator.

The communication protocol uses 10 bytes for signal specification, which controls the mechanical movement of the vehicle. These 10 bytes include the packet header, instruction type, number of data bytes, data segment, extension bits, checksum, and packet tail. The data section of the control signal contains the information that controls the robot's various movements, and the data section of the sensor signal contains the values detected by the sensor.

4. Communication test of inspection robot

In order to verify the feasibility and stability of the communication system design in this article, a section of pipeline in the urban area was selected for field test. The test section is: 110KV UHV Huainan Station, Panji District, Huainan City, Anhui Province, the test pipeline is about 350m long, and the different cover plate settings are numbered Y12-Y19; ambient temperature: the highest temperature outside the pipeline is 36℃, and the average temperature inside the pipeline is 40 ℃. The experimenter places the inspection robot into the pipeline, as shown in figure 6.

![Figure 6. Working diagram of inspection robot.](image)

The inspection robot works normally under the communication system network designed in this paper, and its sensor data and video data are transmitted to the web end, as shown in figure 7.

![Figure 7. Working interface of cable trench intelligent inspection visual platform.](image)
In the experiment, communication delay sampling was carried out for the cable trench robot at every 1m position while 1000 data were sent and received at every 10m position. The packet loss rate was recorded and the graph was drawn as shown in figure 8.

![Figure 8. Communication data sampling diagram.](image)

Figure 8. Communication data sampling diagram.

After adopting the communication system scheme designed in this paper, the experimental data measured by the inspection robot at a distance of 350m from the communication receiving end in the cable trench are shown in table 1. Observed through experimental data, the communication delay of the inspection robot does not exceed 110ms, and the packet loss rate does not exceed 0.5‰.

**Table 1. Communication Performance Indicators.**

| Communication Performance Indicators | Numerical |
|--------------------------------------|-----------|
| Bandwidth                            | 40MHz     |
| Time delay                           | 101ms     |
| Packet loss rate                     | 0.41‰    |
| throughput                           | 22Mbps    |

At the same time, the delay and packet loss rate of the sampled data are used for correlation analysis with SPSS software, and the correlation data obtained is shown in table 2. It can be seen that there is an obvious positive correlation between the packet loss rate and the communication delay. Therefore, the packet loss rate can be effectively reduced by reducing the delay, and the real-time performance and stability of communication can be enhanced.

**Table 2. Correlation analysis.**

|                  | Time delay | Packet loss rate |
|------------------|------------|-----------------|
| Time delay       | Pearson correlation | 1          | 0.990** |
|                  | significance (bilateral) | None       | 0.000   |
|                  | N          | 36             | 36      |
| Packet loss rate | Pearson correlation | 0.990**    | 1       |
|                  | significance (bilateral) | 0.000      | None    |
|                  | N          | 36             | 36      |

** Represents a significant correlation at the 0.01 level (bilateral).

After field tests, the communication scheme designed in this paper is adopted, and the inspection robot can communicate normally, transmit stably, return high-definition images, and no network interruption is found. The communication delay and packet loss rate meet the requirements for smooth data transmission. The real-time transmission of video signals and sensor signals is high, and the robot control sensitivity is high, which can well complete the inspection task of substation cable trench.

5. Conclusion
The application purpose of the substation cable trench inspection robot is to replace the manual inspection in the cable trench. However, due to the complex environment in the cable trench, the
tradition LoRa-based communication system solution cannot make the robot work well, thus limiting the cable Application of ditch inspection robot.

In order to solve the problem of difficulty in wireless communication of inspection robots in the pipeline, this paper designs a wireless communication scheme based on WLAN, using B/S architecture combined with communication hardware design, communication software design and communication protocol design to make the communication system stable and real-time. Greatly improve the portability of the inspection robot. At the same time, the feasibility of this scheme has been verified through field experiments, and it has high practical application value.

For future research, this article puts forward two suggestions:

- For the long-distance communication in the cable trench, the content of this article can be expanded. According to the experimental data, consider the influence of the number of relay routers on the communication quality, and avoid the problem of redundancy of the number of relay routers.
- Fully consider the harm caused by the strong electromagnetic environment in the cable trench to the communication, and carry out the anti-magnetic interference design on the communication hardware, so as to improve the quality of the communication system.

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