Research and application of cable pipeline robot for underground pipeline 3D simulation technology

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Abstract. In this paper, an underground cable intelligent pipeline detection robot is designed for the collection of pipeline position information. First of all, its mechanical structure is developed. In addition, the research of operation control algorithm is discussed. Finally, the digital image and pipeline space coordinate acquisition and communication methods are studied. In the design stage, the design scheme of each module is first determined and researched, designed and improved; then the integration and verification are carried out; finally, the field test and improvement are carried out; the prototype is produced and operated after meeting the conditions of trial operation, and the operation data are actively collected for improvement and improvement.

1. Introduction
With the acceleration of urbanization, power lines and facilities are constantly being updated to meet people's demand for electricity to beautify their lives. In order to further improve the reliability of power supply and enhance the aesthetic appearance of the city, in recent years, the urban distribution network [1] has been gradually transformed from overhead lines to cable lines [2,3]. Although the investment cost of cable line is large, the problem of overhead wire can be effectively avoided by laying the cable line underground. Power facilities such as cable distribution box, switch station and distribution house can greatly reduce the scope and time of power failure, so as to realize the automatic control and self-healing control function of distribution network.

With the large-scale construction of cities, the number of power cables of various voltage grades is increasing, and more and more underground cables are to be laid. Therefore, it is imperative to develop a new and advanced detection tool for cable and pipeline laying to replace the original backward and cumbersome manual labor, improve work efficiency and reduce construction cost.

At present, the international robot community is increasing scientific research efforts, the research of robot generic technology, and towards intelligence can change and diversification direction development. Among them, underground robot mainly includes excavating robot and underground pipeline robot two kinds big. The main research contents are: mechanical structure, walking system, sensor and positioning system, control system, Communication and remote control technology. At present, Japan, the United States, Germany, Japan and other developed countries have developed underground pipelines, oil, sky Gas and other large pipeline maintenance robots, a variety of mining robots and automation systems are being developed. With the development of the world robot technology and the formation of the market, China in the robot science research, technology development. China's industrial robot research began in the 1970s, but due to the weak basic conditions,
key technologies and components not supporting, insufficient market application and other reasons, failed to form a real product. And application engineering and other aspects have made gratifying progress. In the mid-1980s, under the support of the national science and technology project, China's industrial robot research and development entered a new stage, forming a climax of China's industrial robot development. Remarkable achievements have been made in the design and manufacturing technology, control technology, system integration technology and application technology of the industrial robots mainly in welding, assembly, painting and handling, as well as the components represented by AC servo drivers, harmonic reducers and thin-walled bearings, as well as the robot itself. From the late 1980s to the 1990s, the National 863 Program listed robots as an important research topic in the field of automation, systematically carried out the research of basic science of robots, key technologies and robot components, target products, advanced robot system integration technology, and the application of robots in automation engineering. In terms of the selection of industrial robots, the development of spot welding, arc welding, painting, assembly, handling and other robots is determined, and the development of underwater, automatic guided vehicle (AGV), wall climbing, window cleaning, mobile operation in pipe, concrete spraying, tunnel drilling, micro-operation, service, agriculture and forestry and other special robots. At the same time, the company has completed a number of robot automation application projects, such as spot welding of automobile body, arc welding of rear axle housing, welding of motorcycle frame, and robotic three-dimensional warehouse, which is an important step for China's robot industry from development to application. A number of talents and teams engaged in robot research, development and application have grown and strengthened in practice, and a number of industrial bases with robot as the main business have broken through the ground.

Pipeline robot is a kind of advanced pipeline inspection equipment, which is composed of mobile carrier, monitoring system, communication system, power transmission system and control system. Under the remote control of the operator, the robot walks along the pipeline and continuously shoots and displays the images inside the pipeline in real time, which clearly and intuitively reflects the status of the fault points inside the pipeline, which overcomes the disadvantages of the traditional detection methods. This improves the diagnostic accuracy, strengthens the understanding and grasp of the pipeline, and timely and effectively completes the detection, maintenance and repair of the pipeline, showing a huge application prospect. The mobile structure of robot mainly depends on the mobile environment. Mobile robots are mostly designed for land surface environments. Special surface environment refers to the surface environment other than the ground environment (such as wall surface, internal and external surface of pipeline, etc.). The main mechanism forms that can move in the surface environment are: wheel type, crawler type, leg foot type, step type, creep type and snake type and other mobile structures, which are respectively suitable for a variety of different occasions.

Due to the special application of loop scenarios such as cable lines and pipelines, there are many deficiencies in the current pipeline robots both in terms of ontology design and function. Traditional pipeline robots are generally used in large pipelines with a diameter of more than 300mm, and have good sealing performance and less internal sundries. The transmission of things is generally gas or liquid, and the Angle is a right-angle bend, and the corresponding vertical pipe will be more. Therefore, the current pipeline detection robot has larger volume and better climbing performance. For the main role of conveying gas or liquid pipeline, its detection focus is mainly around the detection of the sealing of the pipeline, and the detection focus is completely different from that of the cable line pipeline robot [4]. There is more debris in the pipelines of distribution network cables than in the pipelines that carry gas or liquid. The precise structure of the traditional pipeline robot is difficult to ensure the reliability of its operation in the actual environment of the relatively complex cable line and pipeline. These make it difficult for the traditional pipeline robot to fulfill the requirements of the current distribution network cable line pipeline maintenance [5].

Through analysis and summary, this paper designs a new type of distribution network cable pipeline robot. The purpose is to reduce the material resources and manpower, while improving the efficiency and accuracy of cable line inspection. The cable line pipeline robot designed in this paper can inspect the internal situation of the cable line pipeline, and has the function of image recognition, which
effectively reduces the pressure and burden of the staff and improves the work efficiency. In addition, the cable line pipeline robot adopts caterpillar chassis, which can run well in the pipeline [6].

The content of the paper is outlined as follows. The Section 2 discusses the overall system design. Section 3 gives hardware structure design. In section 4, we give the software system design. Section 5 shows System implementation. Moreover, paper is concluded with some discussions and closing remarks.

2. Overall system design

Cable and pipeline robot is used for cable and pipeline monitoring, cable laying and pipeline cleaning. The robot is driven by a high-power miniature motor and intelligently controlled by a microprocessor. It has enough traction force to cross the cable pipeline with a length of 125 meters. It has strong climbing ability and the ability to pass through curves, and can pull cables weighing more than 10kg to realize the function of cable laying. The enhanced arm structure allows the robot to adapt to different pipe diameters and prevent overturning. Adopt micro-dynamic and static sealing technology to prevent micro leakage. Sealed and waterproof, to meet the requirements of walking through the water depth of 1 meter. High performance corrosion resistant materials are used to prevent the robot from corrosion in the aqueous medium with acid or alkaline.

The robot is equipped with a digital camera module, which is equipped with a wide-angle camera with strong light illumination. It CAN monitor the image situation in front of the tube and the wall, and transmit the digital image to the controller LCD screen in real time through CAN bus. The handheld controller is composed of a power supply module, a microcontroller module, a liquid crystal module, a keyboard and a control panel, etc. It is mainly used to read the array digital images collected by the camera and decode and display them in real time.

The cable unit is composed of wear-resistant and waterproof cable, conductive slip ring, counter, cable winding reel and other parts. The cable duct detector uses high-efficiency power electronics technology to convert and rectified voltage, converting 220V AC to 75V DC to supply power to the robot and handheld controller through the cable. Counter can record the robot running distance.

Traction rope unit is composed of traction polyester rope and winding reel, etc., which is mainly used for retracting traction rope, auxiliary cable laying, and can pull the robot out of the underground drainage pipe in case of accident.

Because the power cable line pipe special application environment, the existing pipeline robot till exists many shortage of place, aiming at the existing pipeline robot structure and control methods have been adjusted, developed a new type of cable for distribution network pipeline robot, reduce material resources and manpower, and at the same time improve the cable line inspection work efficiency and accuracy.

System architecture design is shown in Figure 1.

![Figure 1. Overall system design.](image-url)
3. Hardware structure design
The hardware system of the robot includes two modules: the mechanical design part and the underlying control circuit. As for the modular design idea, the driver of the underlying hardware circuit can be basically cured by the manufacturer, and the focus of researchers has gradually shifted to the upper design and implementation.

3.1. Overall design of hardware
The overall block diagram of hardware design is shown Figure 2 as follows:

![Figure 2. System hardware design.](image)

3.2. Motion control module
Considering the complex environment where the pipeline robot is located, its mobile platform adopts a wheel structure, as shown in Figure 3 the below:

![Figure 3. Overview of the structure.](image)

3.3. Real-time monitoring design
3.3.1. Visual module. Like other autonomous robots, the pipeline robot can sense the information of the external environment mainly through its own sensors. At present, as the function of vision sensor is more and more powerful, more and more cost-effective, the scope of application of vision sensor is more and more extensive. At present, the common vision sensor can be divided into monocular vision, binocular vision and omnidirectional vision. Considering the function realization and cost performance, the scheme design chooses the architecture of monocular vision + pan-head.
3.3.2. **Magnetic field sensing module.** Magnetic field sensing is mainly realized by linear hall element. Here we use AH3503 linear hall element. The circuit consists of voltage regulator, Hall voltage generator, linear amplifier and emitter follower. Its input is the magnetic induction intensity; the output is proportional to the input voltage. The circuit schematic diagram is shown in Figure 5 as follows:

![Figure 4. Schematic diagram of AH3503.](image)

3.3.3. **Temperature sensing module.** Temperature sensing is mainly realized by DS18B20 temperature measuring module. DS18B20 is a commonly used digital temperature sensor, its output is a digital signal, has the characteristics of small volume, low hardware overhead, strong anti-interference ability, high precision. Its circuit schematic diagram is shown in Figure 6 as follows:

![Figure 5. DS18B20 schematic.](image)

3.4. **Lighting equipment solutions**

The camera monitor includes three parts: lighting module, wide Angle lens and digital camera module. The lighting module is connected in parallel with 38 ultra-bright white LEDs and driven by 3.3VDC to provide wide-angle lighting. Due to the particularity of dark light in the circular pipe, the ordinary bright white LED cannot meet the lighting requirements of the system, and the high-power super bright white light emitting diode must be selected. After many tests, it is found that the choice of super bright white and blue LED lighting, can get the best color and brightness effect on the display image. Below is a digital camera module with a wide-angle lens, which is surrounded by an illuminated tube, providing a clear view of the area ahead and inside the tube wall is illuminated by the lighting device.

3.5. **Digital camera module solution**

Digital camera module is mainly composed of wide-angle lens, CMOS image sensor and image processing chip. The images of the front of the robot and the inner wall of the tube are collected in real time, which are converted into digital signals and transmitted to the handheld controller by CAN bus.

3.6. **Handheld controller module solution**

The handheld controller receives the JPEG digital image data from the camera on the CAN bus, and the software decodes it into the corresponding RGB (565) raw data, which is displayed on the LCD. Figure 8 shows the internal hardware structure of the controller.
This chapter introduces the hardware design of the cable line pipeline robot. Specifically for the real-time monitoring of cable line and pipeline robot, the motion mode, temperature sensing, magnetic field sensing and other modules of cable line and pipeline robot system are analyzed and designed.

4. Software system design
As the actuator of the robot, the motion control subsystem of the pipeline robot is divided into two parts: the mechanical part and the underlying control circuit part. The most popular Robot operating system (ROS) operating system is used in the design and implementation of the robot body. ROS is a highly flexible software architecture for writing robot software programs. It contains a wealth of tools, library code, and conventions designed to simplify the process of creating complex, robust robot behaviour across robotics platforms.

ROS is a distributed framework design. Processes can run separately, nodes can run on different computing platforms, and communicate through topic and service, which is convenient for modularized modification and customization, and improves the fault tolerance of the system.

The implementation of ROS-based application layer algorithm must deal with hardware, sensors and actuators. Of course, there are many kinds of communication methods, such as CAN communication, LIN communication and wireless communication, among which the most commonly used is serial communication. ROS also provides the rosserial feature package, which enables the embedded system to interact directly with other nodes as a ROS node, which is more ROS-compliant architecturally. But because some of the ROS libraries need to be ported, embedded developers may need to be familiar with a different set of syntax than they are used to. In addition, the feature pack is the communication medium between the software layer and the hardware layer. Therefore, in a relatively flexible way, we need to write a ROS node in the ROS application layer that communicates with the serial port. This node is responsible for reading the data transmitted by the embedded system to the ROS application layer from the serial port and sending control instructions to the embedded system through the serial port. Finally, the system drives the actual actuator to act. The schematic diagram is given in Figure 7 as follows:
Figure 7. Schematic diagram of industrial computer and Arduino serial communication.

The design adopts the Universal Asynchronous Receiver/Transmitter (UART) communication. UART is the general term for serial asynchronous communication port. The data to be transmitted is converted between serial communication and parallel communication. As a chip that converts parallel input signals into serial output signals, UART is usually integrated on the links of other communication interfaces. UART serves as a universal serial data bus. The bus is bidirectional communication, which can realize full duplex transmission and reception. The communication can be long distance and the program design is simple. The UART communication parameters are set as shown in Table 1.

Table 1. UART communication parameter settings.

| Set the item | Parameter |
|--------------|-----------|
| Baud rate    | 96000bps  |
| Parity bits  | none      |
| Data bits    | 8         |
| Start bit    | 1         |
| Stop bit     | 1         |

4.1. SLAM Based on Particle Filtering

Pipeline robot moves in the unknown environment, its main purpose is to obtain the map information of the environment. There are a lot of ways that maps can be represented. At the same time, due to the errors of sensors and motors carried by the robot itself, the robot is likely to deviate from the target direction in the process of movement. First of all, the robot needs to determine its own position so that it can build the map accurately. However, to build the map accurately, it also needs an accurate positioning. The dependency between mapping and localization makes SLAM extremely difficult and sometimes requires a high-dimensional space search to solve the problem.

As an important problem of robot autonomy, SLAM has been widely studied by many scholars. In 2000, Murphy was geared toward solving SLAM using Rao-Blackwellized Particle Filter, geared toward getting accurate maps, the main challenge with this algorithm is to reduce the number of particles. With the continuous development of ROS system, Gapping has been widely concerned and applied. As an open source SLAM package in ROS in 2007, gapping is the most widely used package in the field of robot entities at present. As a practical algorithm, Gapping can be used both indoors and outdoors and relies on an improved adaptive RBPF algorithm for mapping and positioning.
RBPF is an effective algorithm for simultaneous localization and mapping. The key point is that RBPF can achieve the separation of localization and mapping. The disadvantages of RBPF are large number of particles and frequent resampling. As we all know, excessive number of particles increases memory consumption, and frequent resampling results in particle degradation. Gmapping improves the proposed distribution and resampling on the basis of RBPF algorithm, and reduces the number of particles and degradation. The new proposed distribution considers both odometer information and observation information. Resampling can only be performed when the weight of particles changes beyond the set threshold by setting a threshold value, thus greatly reducing the number of resampling times.

4.2. Roboware studio
The design uses Roboware Studio as the development platform. Roboware Studio is an integrated development environment dedicated to ROS development and debugging. The goal is to help ROS developers, reduce development difficulty, and improve development efficiency. For developers, it can help those in the field of robotics to quickly integrate the rich software resources of ROS.

4.3. Upper computer software design
The upper computer uses Raspberry Pi 3B+ to communicate with PC. Because ROS is open source, the development of ROS robots does not require the development of the software from the underlying driver to the upper application as before. Based on the excellent ROS, the main work of this design in the software is: PC keyboard control robot movement and control camera head, Raspberry Pi and STM32 serial communication, RVIZ on the point of failure marking.

4.4. Lower computer software design
The lower computer uses STM32 controller to control the two-degree-of-freedom head, temperature sensor and magnetic field sensor of the camera mounted on the robot.

In this chapter, the communication protocol of cable line and pipeline robot is studied and discussed, and the software of upper and lower computers is analysed and designed.

5. System implementation
This paper designs a cable pipeline robot, which is used for underground cable pipeline maintenance work. By placing aluminium, iron and boron magnets to simulate the strength of the magnetic field caused by cable breakage in the pipe. The operator operates the car in the pipeline to observe the surrounding environment through the camera, and judges whether there is any fault point by combining the real-time data of magnetic field strength sensor and temperature sensor. Where the magnetic field strength and temperature are too high, the pipeline robot will automatically mark on the RVIZ. Save the map and trouble point information after finishing [7].

![Figure 8. Cable pipeline robot.](image)

The total mass of the robot as shown in Figure 8 is 5 kg. The forward speed can be adjusted freely between 0-10 meters/minute, the endurance time is 40 minutes, and the cable communication distance in the underground pipeline is 1000 meters.
6. Conclusion
With the continuous expansion of the coverage of urban cable pipeline, in order to ensure the reliability of urban power supply, the level of inspection and maintenance of cable pipeline needs to be constantly improved. The fault of cable pipeline is mainly caused by various sundries accumulated in the pipeline. With the development of science and technology, robot maintenance, as a relatively intelligent method, has attracted more and more attention.

The main work of this paper is as follows:
(1) This paper introduces the research background and significance of cable line pipeline robot in distribution network, research status at home and abroad, research objectives and research contents of cable line pipeline robot in distribution network.
(2) System overall design, the design of distribution network cable line pipeline robot architecture, and briefly introduces the pipeline robot system composition, including lower computer, upper computer and sensors.
(3) Hardware structure design, the cable line pipeline robot hardware design is introduced in detail, mainly for the cable line pipeline robot real-time monitoring module, movement mode, temperature sensing, magnetic field sensing module is analysed and designed.
(4) Communication protocol and control software design, the cable line pipeline robot communication protocol analysis and design, the upper and lower computer software analysis and design.
(5) System implementation, the implementation of distribution network cable line pipeline robot is analysed and studied, the initialization and operation of the module is analysed and simulated detection, and the module is combined with the test and joint debugging.

The realization of this design goal will have the following significance: on the one hand, it reduces the pressure risk of high-voltage wire workers entering the underground cable pipeline for maintenance work. On the other hand, the use of robot maintenance, can perceive more abundant information.

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