Control Strategy of Pipeline Robot

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Abstract. The detection of pipeline in service is very important, but the existing manual detection has blind spots, long cycle, high risk, low precision and high cost. Therefore, it is very important to develop a mobile detection robot to replace manual inspection. This paper mainly introduces the control strategy of pipeline robot. In this paper, the overall control structure of the pipeline robot system is built, including the design of hardware framework and the design of software implementation process. Hardware design includes the selection design of microcontroller ARM, sensor, motor driver and so on. The software design is mainly the process design of action realization and the frame design of man-machine interactive operation panel structure. After the system construction is completed, the motion control experiment of the pipeline robot control system is carried out to test the walking performance of the pipeline robot prototype in the vertical variable diameter pipeline, and the motion control experiment is carried out to verify the rationality of the mechanical structure of the pipeline robot and the practicability of the control system.

Keywords: Pipeline Robots, Control Strategies, Human-Machine Interaction, Pipeline Detection

1. Introduction
In recent decades, China's pipeline has been more and more widely used in oil transportation, natural gas transportation and water resources transportation. With the progress of science and technology, the development of industry and the improvement of economic level, China's transportation pipeline construction has made great achievements under the support of national policies. In terms of oil and natural gas transportation, compared with traditional transportation methods such as cars and trains, pipeline transportation is more economical and safer, and rarely causes environmental pollution. However, the corrosion, perforation and rupture of oil or natural gas pipeline will lead to oil or natural gas leakage, which will cause pollution to the surrounding environment, and even cause fire, explosion and other serious consequences, resulting in huge economic losses. In order to ensure the safety of people's lives and property, the stability of social environment and the natural environment are not damaged, it is very important to carry out regular inspection of oil and gas pipeline. At the same time, China's laws also explicitly stipulate that fuel oil transmission pipeline, natural gas and other gas pressure pipeline belong to special equipment, which should be regularly inspected comprehensively. The pipeline robot can detect and locate the location of pipeline corrosion, perforation and crack through the non-destructive testing device and positioning device for pipeline defects carried by it [1].
The pipeline robot can also use the maintenance equipment it carries to carry out maintenance, spraying, interface welding, foreign body cleaning and other work on the pipeline quickly to ensure the pipeline can work unimpeded [2].

When the robot works autonomously, it needs to perceive the surrounding environment, so as to plan the movement path online and avoid obstacles. On the other hand, the robot structure inevitably has machining error, clearance, elastic deformation, vibration, control error and other factors, which will affect the accuracy of robot movement and the effectiveness of claw clamping, so real-time adjustment and correction are required [3]. Riser6 developed by Carnegie Mellon University adopts a distributed signal processing mode. Each leg is equipped with a controller of C8051F021 core. The signals from each sensor are transmitted to the upper computer through RiseBus. At the level of control algorithm, RISE adopts behavior-based control and operates in an open-loop gait, while the lower closed-loop control ensures the contact force between the foot and the environment [4].

The perfect and mature pipeline robot is developed to replace manual operation, which can improve the accuracy and reliability of pipeline inspection and pipeline operation, improve the work efficiency, and extend the service life of oil and gas pipeline. In order to better adapt to the complex structural environment inside the pipeline and work stably and efficiently in the pipeline, the robot needs to have good driving ability, turning ability, obstacle crossing ability and diameter changing ability.

2. Control Strategy of Pipeline Robot

2.1 System Working Principle

For a working device, there are three components:

(1) Embedded system hardware. Embedded hardware is the hardware foundation of the device and provides system software and configuration software.

Platform and support, and directly affect the stability and performance of embedded system.

(2) Embedded system software. Embedded software is an important part of system operation, and its main function is to carry out tasks.

Scheduling, memory management, etc.

(3) Configuration software. The role of configuration software is to provide an application editing platform to complete the design of the application.

Design platform, the role of the application is parameter configuration, data storage, etc.

In order to meet people's increasing system requirements, the dynamic configuration and fault tolerance of distributed system, as an important part of the system operation, has become the focus of more and more researchers. The development of human-computer interaction system is usually completed by coding [5]. Before the system development, first of all, the embedded device needs the processor selection, and then according to the selected processor and the need to complete the function, such as the interface requirements, communication system formulation, the use of peripheral interface, choose the appropriate development language and tools. With edit code development system is a complicated and tedious work, and for a system, function of each module and need a lot of code to achieve, and when the system problems, it is difficult to to solve problems caused by the reason, whether in the development and ability to solve problems for developers demanding [6].

\[ T = a + \log_2 \left( 1 + \frac{D}{W} \right) \]  \hspace{1cm} (1)

All the problems mentioned above have been solved well in the configuration human-computer interaction system. Almost all the functions in the configuration human-computer interaction system are realized through the graphical interface. In the configuration human-computer interaction system, the corresponding graphics are selected from the graphics library to draw the interface, in which the graphics in the interface can be enlarged, dragged and so on to make the layout reasonable, to achieve the required functions and effects; When customizing the communication protocol, the dialog box can be set to achieve the desired effect. The configuration software needs an executable file to run in the
embedded device. When all the required functions are drawn in the configuration software, the configuration software compiles and generates an executable file, and then copies the executable file to the embedded device for running. This development method reduces the development work, improves the development efficiency, and provides a secondary development environment [7].

The upper layer of the configuration human-computer interaction system is the application layer, including graphics library, database and script analysis, while generating executable files as configuration software. The graphics library of structures, the human-computer interaction interface provides a convenient conditions, the database is also a necessary part of the layer, the database for the data read, storage, and data view provides conditions, in addition, the configuration software running on embedded devices need to scripting language, so the application layer also need to scripting language parsing analysis [8].

\[ T = a + b \log 2(n) \]  

(2)

The middle layer of configuration human-computer interaction system is embedded operating system, including operating system kernel and hardware driver, which plays a particularly important role in human-computer interaction system. This layer has the functions of task scheduling, memory management, interprocess communication and file storage system. Embedded operating system plays a connecting role in the whole human-computer interaction system, communicating with configuration software upward, interacting with operators, and controlling embedded hardware devices downward.

The lower layer is embedded hardware equipment, including power supply, microcontroller, display equipment, storage equipment, communication equipment and other modules, when the industry has other needs, can also be expanded to its I/O port. Embedded hardware equipment provides the support for the software operation, but also determines the stability of the whole system.

2.2 Operating System
(1) Control system framework

The master control system consists of the host computer and the master controller, which communicate through TCP/IP protocol in the same wireless local area network. Among them, the upper computer processes and displays the detected information and also sends instructions to control the operation of the robot. The main controller communicates with the ultrasonic guided wave detection board and motion drive system through CAN bus to control the detection operation and climbing movement. Attitude and environmental information measured by the sensor system are received through 485 serial port [9-10].

The detection system is composed of infrared camera, ultrasonic guided wave detection board and guided wave probe. The infrared camera shoots the pipeline environment in real time and sends it to the upper computer through TCP/IP protocol. On the one hand, it is for the reference of maintenance technicians. On the other hand, the pipeline structure parameters are obtained through image processing to guide the robot to move. The ultrasonic guided wave detection board controls the guided wave probe to send out the ultrasonic guided wave in the pipeline, and receives the echo signal, and obtains the defect information of the pipeline through signal processing.

The motion drive system consists of a driver, a motor and an encoder. The motor is divided into a rotary joint motor to control each joint and a gripping joint motor to control the gripper. The driver sends instructions to control the motor movement, and the encoder detects the actual rotation of the motor for feedback control.

The sensing system is composed of infrared camera, acquisition card, inclination sensor, ranging sensor and pressure sensor. The pipeline image taken by the infrared camera is processed by the upper computer and then the pipeline structure parameters are sent to the main control board. The inclination sensor, distance sensor and pressure sensor send the measured signal to the acquisition card through TTL level, digital port and analog port respectively. The acquisition card packages the data and sends it to the main control board through the 485 serial port for motion planning.

(2) Layered control strategy
In motion control, the layered control strategy is adopted to control the motor of each joint. The planning layer is the outer layer of the motion control system. According to the task requirements and the actual environment, the gait can be selected to determine whether there are obstacles and the location of obstacles. The main controller obtained the required motion Angle of each joint through motion planning, and then calculated the time Angle sequence of each joint through trajectory interpolation. The servo layer sends instructions to control the rotation of each joint motor to reach the final position and pose; According to the autonomous correction model and correction method described in Chapter 3, the robot position error is detected by the sensing system and fed back to the master controller. Calculate the required compensation Angle of each joint, correct the error, and accurately move to the target position.

(3) Motion drive system
The motion drive system of robot is the base of robot climbing operation. The rotary joint adopts the brushless DC servo motor EC-MAX 30 of Maxon Company with Hall sensor, which is combined with the planetary gearbox GP32 HP and the incremental photoelectric encoder HEDL 5540, and is controlled by the brushless DC servo driver MLBLDS 3605 of Minglang Technology.

3. Motion Control Experiment of Pipeline Robot
The main part of the pipeline robot control system is the handheld display control platform. According to the design scheme of the pipeline robot control system, the handheld display control platform verifies the operating system installation, serial port communication, video signal acquisition, upper and lower computer communication and other functions on the premise of the completion of hardware construction.

By operating the upper computer interface of the hand-held display control platform, instructions are sent out, and the robot starts, stops, speed regulation and reversing are controlled by serial communication.

First of all, click the power button of the handheld display control platform to energize and start the control system of the pipeline robot. The system will conduct self-check. If the self-check fails, the system will alarm and exit the system to troubleshoot. If the self-check passes, try to establish communication. If the communication fails, a warning window will pop up and exit the system. If the communication is established successfully, further experiments will be carried out to verify the safety protection function of the system. Then, in the operating system, the camera is turned on through the key control, and the walking device is controlled to walk in the experimental pipeline, so as to verify the speed regulation and reversing of the walking device. At the same time, the state of the experimental pipeline is detected by real-time feedback video signal, so as to verify the start-stop, speed regulation and reversing functions of the pipeline robot. Then, during the operation of the robot, click the button to verify functions such as taking photos, recording videos, enlarging local images, etc., and store data after taking photos or recording. Finally, recover the walking device to the starting point, turn off the power of the walking device, turn off the camera, exit the system, and complete all the operations.

4. Test Result

4.1 Motion Control Experiment

| Pipe diameter | Maximum speed | Maximum traction |
|---------------|---------------|-----------------|
| 200           | 36            | 47.9            |
| 180           | 40            | 74.6            |
| 150           | 63            | 132.4           |
| 130           | 44            | 133.7           |
| 115           | 35            | 55.7            |

Table 1. Robot parameters
As shown in Figure 1 and Table 1, the pipeline robot prototype can independently complete forward, backward, stop and other actions in pipelines of different pipe diameters, and maintain good contact between the supporting legs and the inner wall of the pipeline. At 150mm, the speed is 63rpm and the maximum traction is 132.4N. At 100mm, the rotation speed is 22rpm and the traction force is 42.6N. The maximum mass of the pipeline robot and cable is 2.3kg, so there is enough traction force for the large pipeline robot prototype to move in the vertical pipeline cable. In addition, the large pipeline robot prototype runs smoothly in the working process, and will not slip or get stuck, which can better achieve the predetermined goal. Meanwhile, it also proves the rationality of the structural design and control system in the scheme and the reliability of the small pipeline robot prototype in the crawling process.

4.2 Robot Exercise Distance
As shown in figure 2, the robot in the cylinder delay under 300, 500 and 700 ms, in a certain time range comparison chart, you can see in time delay, the robot's basic maintain average speed, the time delay, the greater the average speed is smaller, the distance curve of the sawtooth shape, the more obvious, thus it can be got, when in the rotation of the oscillating frequency and the frequency of electromagnetic valve is large enough, by reducing delay time, the basic can realize continuous walking robot.

5. Conclusions
In this paper, the control strategy of pipeline robot is studied, the hardware architecture of the handheld display control platform is designed, and the integrated controller is controlled by writing the upper computer interface. The integrated controller circuit is developed with STM32 as the core. According to the working principle of DC motor, the control program of lower computer is written with software, so as to complete the construction of the whole control system. On the basis of the completion of the system construction, the motion control of the pipeline robot control system was experimented, and the walking performance of the pipeline robot prototype in the vertical variable diameter pipeline was tested. The rationality of the robot structure and control system was verified through experiments. In China, the development of pipeline robot started late, but with more and more researchers devoted to this promising career, the development of domestic pipeline robot has made rapid progress. The pipeline robot studied in this paper is simple in structure and convenient in design, but for practical application, there are still many areas that need to be improved.

Acknowledgments
This work was financially supported by Research and Application of Underground Pipeline 3D Simulation Technology Based on Cable Pipeline Robot.

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