Design of city sewer dredging robot with variable diameter

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Abstract. The cleaning of city sewers has always been a problem that has plagued the daily life of urban residents and the industrial production. In this paper, a cable-free double-track sewer dredging robot with variable diameter is proposed for dredging and detection of city sewers. The system composition and working principle of the dredging robot are described, and the key technologies of the robot walking in the square and circular pipe are studied. In addition, the dredging system driving scheme of the pipe robot, coordination mode between the dredging manipulator and the reamer mechanism and sludge treatment scheme are designed, and the capsizing of the robot in the working state is described. Finally, the control module of the pipe dredging robot is designed. The city sewer dredging robot designed in this paper can autonomously walk in the city sewers and carry the machine vision equipment and dredging equipment to complete the dredging of sewers. The design in this paper provides a new feasible solution for the cleaning of sewers in city.

1. Introduction

At present, cities at all levels in China are in an era of rapid development and change [1]. The daily domestic garbage and various types of plant waste are discharged with the underground pipelines, to avoid the pollution of the environment as far as possible. However, just due to the disposal through sewer pipes, such garbage and waste are accumulated over a long period in sewer pipes, resulting in siltation or blockage. If the sewer pipes cannot be effectively cleaned and dredged in time, it will cause the pollution to the environment and may even affect the health of residents. The cleaning of sewer pipes has become an important task of environmental protection departments and the changes in the cleaning method are also drawing more and more attention [2, 3].

The sewer dredging robot may be divided into the wheeled pipe robot [4], tracked pipe robot [5], squirmy pipe robot [6] and legged pipe robot [7] based on the walking mode. In western countries, the research on sewer robots started earlier. Some of their products are on sale for practical dredging work, especially the wheeled sewer dredging robot, for example, the Perapoint P600 pipe inspection robot [8] developed by Radiolocation, with the traction force of 35kg. RoboProbe Technologies Inc.’s series of products [9] are a typical representative of the tracked pipe robot and this series of robots are mainly used for the detection of pipes with the small diameter usually of 100mm–900mm. The squirmy pipe robot, for example, the MAKRO pipe robot developed by the German GMD Institute [10], is applicable to sewer pipes with the large diameter, slight siltation and complicated internal structure. It walks mainly through the radial extension movement; the speed is very slow, the detection efficiency is very low, and the sealing performance is not good enough; therefore, it should not work in wet conditions for a long time. The legged pipe crawling robot MORITZ [11] developed by Technische
Universität München has a dead weight of 20kg, a drive capability of 15kg and a maximum walking speed of 0.1m/s. The disadvantage is that the control is too complicated and the drive efficiency is not high. In China, the research on pipe robots started relatively late and the typical examples include Harbin Institute of Technology [12], Shanghai Jiao Tong University [13], Tsinghua University, Zhejiang University and Tianjin University [14]. But there is still no relatively mature promotion and application in the market at present.

In this design, the main task of city sewer dredging robot is to clear the sludge and sediment in the pipes, and to detect the damage inside the pipes and carry out simple maintenance. The preliminary work is mainly to research key technologies of the robot walking in the pipes, including the analysis of starting, acceleration, change direction and obstacle crossing. The research mainly aims at the adaptability of multi-diameter robot and the design of dredging system.

2. Overall structure design of pipe dredging robot
The overall research process of the city sewer dredging robot in this project is shown in figure 1.

![Figure 1. Overall Research Process of Dredging Robot.](image-url)

2.1. System indicators and composition of pipe dredging robot
According to the statistics, the inner diameter of city sewer pipes in China ranges from 300mm to 2000mm [15] and 80% of the sewer pipes have an inner diameter of 600mm–800mm. The maximum distance between two adjacent inspection wells is generally 50m and the inner slope in the pipe is generally 1%–5% [16]. Based on the analysis of relevant indicators of research contents in this project, the system indicators of pipe dredging robot are shown in table 1.

| Operation Capability | Control Mode |
|----------------------|--------------|
| Adaptive diameter | Weight source |
| Movement speed | Internal power supply |
| Weight bearing capacity | Communication mode |
| Single operation distance | 485 |
| Weight | communication |
| 0.6~1.0m | 20–25 kg |
| 2~10 m/min | (<45m for others) |
In the energy supply, there are cable and cable-free pipe robots [17]. Although the cable robot has stable energy supply and storage, the friction between the cable and the pipe wall may affect the robot walking and the operation space when the walking distance is far or there is a turn in the pipe [18]. The cable-free robot has limited energy storage, which is greatly affected by the quality of the battery, but its energy will convert the energy of the liquid in the pipe so that the robot can flexibly change the direction and moving posture in the pipe [19].

Therefore, the cable-free pipe robot movement is selected in this design. This city sewer dredging robot consists of the mechanical body, control system, walking mechanism and detection device. The walking function of the robot is realized by the front-wheel drive mode. The dredging work will be completed through the combination between the reamer mechanism and the dredging manipulator arranged in the front end of the mechanical body. In addition, an infrared camera is installed above the body to monitor the internal conditions of the pipe in real time and send the monitoring results back to the control terminal.

Based on the above performance indicators, the overall design of the city sewer dredging robot system is shown in figure 2.

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2.2. Design of walking mechanism

The walking mechanism of the pipe robot is driven by the motor and is transmitted from the driving gear to the driven bevel gear. Because the drive ratio of chain drive is relatively stable and the transmission efficiency is relatively high, the power is transmitted through the engagement of the sprocket tooth with the chain link in the chain drive to form a differential structure, to drive the track to work, forming the main drive system of the robot, as shown in figure 3.

At the same time, considering that the walking environment of the robot in the sewer pipe is poor and there may be a certain depth of siltation, the tank type track design is used to ensure its good walking function and obstacle crossing capability. The appearance is shown in figure 4 and the overall structure of the sprocket engaged with the track is shown in figure 5.
2.3. Design of variable diameter structure
When the dredging robot operates in a circular pipe, it is necessary to consider the operating attitude under different inner diameters [20, 21]. To adapt to circular sewer pipes with different inner diameters and make the contact area and positive pressure of the track and the inner wall of circular pipe large enough, the robot interacts with the spring via a sliding rod mechanism connected with the gear and adjusts the track wheel attitude to realize the variable diameter. The sprocket fixing plate is connected with the shell of the pipe robot through a connecting shaft. The other end of the connecting shaft is a rotary pair, and one end of the spring is fixedly connected with the rotary pair and the other end is fixedly connected with the bevel gear shaft end. By extending and compressing the spring, the angle of the connecting shaft to the fixing plate is adjusted so that the size of the robot in the width direction can be changed. When the pipe diameter increases, the spring extends, the angle between the two connecting rods of the rotary pair changes and the sliding rod slides outward, to drive the track to expand out as the sprocket fixing plate is fixedly connected with it; therefore, the width of contact with the bottom of the pipe increases; on the contrary, the spring compresses and the sliding rod shrinks inward to drive the track to move inward; therefore, the contact width between the robot and the bottom of the pipe reduces.

By adjusting, the dredging robot can be applied to the operation in the pipe with the diameter of 600–1000mm. As shown in figure 6, (a) and (b) are the working states of the pipe robot adapted to the small pipe diameter and the large pipe diameter respectively.

![a) Pipe Robot Adapted to Small Pipe Diameter](image1)

![b) Pipe Robot Adapted to Large Pipe Diameter](image2)

**Figure 6.** Variable Diameter Structure Diagram of Pipe Robot.

3. Research on key technologies of dredging system of pipe robot

3.1. Design of dredging manipulator
Figure 7 shows the dredging manipulator diagram of the pipe robot. The manipulator can move to the front, the side and the rear of the robot body by controlling the movement of the manipulator with two sliding rods, to realize the dredging by the manipulator. The end-effector structure is shown in figure 8. The rack extension is controlled by a miniature hydraulic power unit and the engagement of the gear with the rack is used, so that the grasping force is large and it is more stable, which helps it grab a few stones or large garbage.

![Figure 7. Dredging Manipulator Diagram.](image3)

![Figure 8. End-effector Diagram.](image4)
3.2. Design of reamer system
The reamer mechanism is arranged below the manipulator and driven by the motor. Due to deposition of sludge in sewer pipes, the garbage is stacked and gradually thickens or even hardens. Although the dredging manipulator can grab large and soft garbage, it can do nothing for the hard and stacked garbage. At this point, the reamer mechanism can play its function, that is, the reamer can loosen the deposited and hardened garbage and can cut some large objects to facilitate the mechanical gripper to grab them [22, 23]. The reamer mechanism rotates under the drive of the motor and it will cut, block and dredge the garbage to facilitate the dredging manipulator to grab the garbage during the rotation, so that the reamer mechanism can better cooperate with the dredging manipulator to finish the cleaning work.

3.3. Design of sludge treatment scheme
In this design, the mode of mechanical smashing and conveying is used [24]. The reamer mechanism will be used to cut some large garbage without completely smashing. The dredging manipulator loads the sludge and the like into the sludge storage box of its own body (the box can accommodate up to 10kg of the sludge), and the robot transports the sludge to the discharge outlet of the inspection well and a container with the lifting lugs is provided outside the box, so that the container with garbage can be transported to the ground to discharge the garbage in the form of lifting at the discharge outlet; while an empty container is placed in the box so that the robot returns to continue the dredging work. The design avoids the process of completely smashing the sludge and simplifies the structure of the dredging robot, to achieve the purpose of conveying and smashing the sludge synchronously and conveying the sludge in batches, thus avoiding the use of a large amount of water, so that the dredging robot is not required to be provided with a water tank to reduce the weight and volume.

4. Research on capsizing of robot in the dredging state
When the pipe dredging robot is used to perform the dredging operation, the center of gravity of the robot may be changed due to the different positions of the dredging manipulator at various orientations of the robot, which may cause the rolling of the robot [25]. Therefore, to understand the best working state of the dredging robot, it is necessary to analyze its operating state in all directions to ensure the reliability of the working of the robot. The working status analysis of the robot is shown in figure 9-14.

Figure 9. Manipulator Reaching the Front of the Body Horizontally.

Figure 10. Manipulator at the Minimum Working Position in Front of the Body.

Figure 11. Manipulator behind the Robot Body.

Figure 12. Manipulator at the Minimum Position behind the Robot Body.
Therefore, the charts above show that:

(1) When the dredging manipulator works in front of the robot body, it is favorable for obstacle crossing;

(2) When the dredging manipulator works in the side of the robot body and the center of gravity is shifted in the tilt direction of the robot, it is favorable for anti-capsizing.

5. Conclusions

Based on the analysis of dredging and detection status of sewer pipes in cities at home and abroad, the structure design scheme of the cable-free autonomous double-track pipe dredging robot with variable diameter is proposed for the size of sewer pipes, type of sediment and internal environment in our country. The robot can walk autonomously in the square or circular sewer and achieve the dredging function.

(1) In this paper, the system structure of the pipe robot for dredging and detection of sewer pipes is clarified, the structure design scheme of the double-track pipe dredging robot with variable diameter is proposed, and the robot is battery-powered without any external equipment or cable transmission, so that the robot can be operated more flexibly, greatly improving the dredging efficiency.

(2) The system structure, walking mechanism and dredging mechanism of the pipe dredging robot are designed and analyzed in detail, and the sliding rod connected to the gear in the chassis will cooperate with the spring mechanism, so that the robot can be adapted to the dredging of circular and square pipes with different pipe diameters, improving the adaptability of the pipe robot to the environment.

The innovation of this design is that:

(1) The robot can be adapted to the dredging of different pipes with the diameter of 600-1000mm through the cooperation of the sliding rod connected to the gear with the spring;

(2) The reamer mechanism is provided to cooperate with the dredging manipulator, to make the dredging more efficient and thorough.

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