An underwater intelligent detecting robot for the inverted siphons in South-to-North Water Transfer Project

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Abstract: This paper introduces an underwater intelligent detecting robot for the inverted siphons in South-to-North Water Transfer Project. Compared with the detecting robot designed for the aqueduct in South-to-North Water Transfer Project, the detection requirements of inverted siphons are much more challenging, caused by the high pressure and fully closed environment characteristics of the inverted siphon itself. Therefore, this newly designed robot should be a fully automatic machine that can be remotely controlled with a wired power supply and signal transferring system. Furthermore, the cameras require 360° observation of the siphon, and no water leakage is allowed during the detection. With these design criteria, we have redesigned a brand new underwater intelligent detecting robot, which can detect and evaluate surface cracks in real-time through remote manipulation.

1. Introduction

The inverted siphons in South-to-North Water Transfer Project are used to convey canal water by gravity under roads, railroads, other structures, various types of drainage channels, and depressions [1, 2]. They are widely used for irrigation and water conveyance. It is mainly made of masonry, concrete and reinforced concrete. In the South-to-North Water Transfer Project, inverted siphons play an important role in water delivery. However, owing to long-term service, cracks will appear in the inverted siphon body, leading to water leakage and damage after long-term service. At present, there are many treatment schemes for various defects, but the main method to find defects is still through manual detection [3, 4]. For example, divers are used to observe underwater to find the location of cracks and seepage, and manual inspection is used to check the surface defects of the siphon body. For the aqueduct, although manual operation is low efficiency, high cost and high risk, it works when necessary [5]. However, for inverted siphons, manual operation is too dangerous, and divers need to suffer under high water pressure and long distances. Therefore, finding a safe method to replace manual operation is urgent. In 2019, we designed an underwater intelligent detecting robot for aqueduct detection, and the latest results show that the entire detection process is highly simplified, the detection success rate is improved by digital image correlation (DIC) technology, and the detection risk is reduced. However, the robot can only be used to detect the side surfaces and the ground surface. For inverted siphons, the
detection requires 360° full field observation, and the robot need to work under more than 20m water pressure. Moreover, the remote manipulation and signal transferring through long distance (about 5km) are challenging. In this paper, we first compared and analyzed the working conditions and detection requirements for both the inverted siphon and aqueduct in section 2. In section 3, the underwater intelligent detecting robot for the inverted siphon in South-to-North Water Transfer Project is introduced, including the hardware and the control system. In section 4, we give our conclusion and prospect.

Figure 1. The view of Qi river inverted siphon.

2. Detection requirements of inverted siphons
Inverted siphon means that when the elevation of the water conveyance channel is close to that of the road or ditch, which in the plane intersection, it is necessary to build a channel structure to make the water pass through the road or ditch beneath, as Figure 1 shows. In fact, it is a kind of pressure water pipeline through valleys, rivers, roads, and other channels. For example, the Yellow River Crossing Project in the first phase of the middle route of the South-to-North Water Transfer Project is the largest inverted siphon project in China. The inverted siphon is composed of inlet section, pipe body and outlet. In fact, quite number of inverted siphons are divided into seven parts according to the needs of river and channel flow, icing and midway water withdrawal in northern China. The seven parts are: inlet transition section, inlet maintenance gate, pipe body section, outlet control gate and outlet transition section, water retreat gate and ice discharge gate [6]. Here, the working area does not include the water retreat gate and ice discharge gate, as shown in Figure 2 [7].
Figure 2. The schematic diagram of an inverted siphon.

Compared with an aqueduct, an inverted siphon has the following characteristics. First of all, an inverted siphon is a closed conduit, so that the inner section of the siphon is dark all time, and it is a challenging issue for signal transferring and remote manipulation. Secondly, unlike aqueducts, the siphon pipes flow under pressure and must have flow velocities greater than a certain value to keep material suspended. Last but not least, an inverted siphon can provide high water pressure, which cause difficulties for the waterproof of all electronic devices. The following table summarizes the advantages and disadvantages for both inverted siphon and aqueduct detections. Therefore, the robot must be designed as a fully automatic machine which can be remotely controlled with wired power supply and signal transferring system. Also, the camera can observe the siphon 360°. Finally, no water leakage is allowed during the detection.

| Detection object | Advantages                      | Disadvantages         | Detection requirements          |
|------------------|--------------------------------|-----------------------|-------------------------------|
| Inverted siphon  | Relative short distance         | Closed tube           | 360° Full field Observation   |
|                  | Large working area              | High pressure         | Wired control                 |
|                  |                                 |                       | Fully automatic               |
| Aqueduct         | Open chamber                    | Long distance         | 270° Observation              |
|                  | Manual interruption is possible |                       | Wireless control              |

3. Solutions for inverted siphon detection

In the following, we introduce our solution for the remotely controlled inverted siphon detection solution, which include an inverted siphon detecting robot and the corresponding control unit. With such solution, one can safely gathered the critical information of the cracks and damages of an inverted siphon.

3.1 Inverted siphon detecting robot

The detecting robot includes three main parts: the traveler, the main body, and the observation head. The schematic diagram is shown in Figure 3. After considering the surface of the inverted siphon might muddy, a customized rubber caterpillar band driven traveler is designed to drive the robot, so that the robot can walk in the inverted siphon, especially for the slope section, without slip. Also, the turning mechanism of caterpillar band driven traveler is simpler than the traditional wheel driven turning mechanism. To turn the machine, one can adjust the spinning difference between two bands, like a tank.

The observation head of the robot include 12 high definition digital cameras, so that it can observe
three sides of an inverted siphon (left, right and upper sides). For the bottom side of the inverted siphon, we have attached three digital cameras on the bottom of the main body. With this so-called “360° visual system”, the robot can observe the full field of the inverted siphon.

Finally, for the main body, it has two functions, one is storing the control unit of the robot. The other function of the main body is up-and down mechanism. For the control unit, we use welding technic to ensure waterproof of the storing box, and we use pressured rubber band and epoxy to seal the connected wires. For the up-and down mechanism, the observation head can reach the upper bound of the inverted siphon so that one can capture more detailed pictures of the detecting surfaces, as shown in Figure 3.

![The schematic diagrams of the two forms of the inverted siphon detecting robot.](image)

3.2 The control system

Figure 4 illustrate the controlling sequence of the inverted siphon detecting robot. To ensure the reliability and accuracy, and to avoid disturbance, the driving system and the capturing system are separated. For the driving system, the operator in the ground control center can send the signal through the remote controller, then the signal will go through the switchboard and transfer to PLC controller. With the PLC controller, different commands can be sent to four different frequency transformers. The first and the second frequency transformers are designed to control the speeds of two caterpillar bands, one for the left band and the other for the right band. The third frequency transformer is designed to control the motor of up-and down mechanism. The last frequency transformer is designed to control the roller of wires, to ensure no wire disturbance happened during the detection. For the capturing system, the captured pictures will be automatically stored in the capturing computer. This is because the limited transferring speed between the ground control center and the underwater robot cannot guarantee that all the captured pictures can be transferred to the computer in time. Therefore, during detection, the AI program will automatically pick the critical pictures which indicate cracks and damages, and then only transferring these picked pictures and the corresponding location information to the remote computer. So that one can see the cracks and damages directly from the ground control center.
4. Conclusion
In this paper, we have introduced the necessity of an underwater intelligent detecting robot for the detection jobs of the inverted siphons in South-to-North Water Transfer Project, followed by the illustration of the hardware and the control system of the robot. With this robot, we give a possible solution for safety detection of inverted siphons, and we could foresee that more and more detecting robots will be designed and performed in such large engineering projects.

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