Design of an Intelligent Inspection Robot for Underwater Pipelines

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Abstract. This paper will introduce the design of an intelligent inspection robot for underwater pipelines. The whole device is divided into detection module, control module, drive module and housing. Among them, the detection module is the camera and the head, the control module is mainly the Raspberry Pi motherboard, the drive module includes the battery, motor, motor driver. The device through the camera module feedback to the Raspberry Pi to make decisions, and this decision through the IO port output, and then through the motor drive module to drive the motor, the motor to make speed and direction of adjustment. This device is proposed to use stepper motor for robot movement method.

1. Introduction of Robot Design Content
This paper designs a robot for intelligent inspection of underwater pipelines, which is used to realize the function of detecting and alarming adsorbed materials on the pipelines and removing and recovering them.

The size of the robot cannot exceed 500×400×300 (mm). The structure of the in-water robot is allowed to be designed in a collapsible form, but it can unfold itself only after it starts to operate. When the underwater robot detects the sorbent alarm, the sorbent should be in the vertical projection of the underwater robot (i.e. the front end of the underwater robot exceeds the sorbent, or the end of the underwater robot does not exceed the sorbent), and the robot should adopt the flashing alarm method, and the flashing color can be adjusted for different shapes of sorbents, such as red, blue, green, yellow, etc.

2. Device Module Analysis and Design
The device as a whole is divided into detection module, control module, drive module and housing. Among them, the detection module is the camera and the head, the control module is mainly the Raspberry Pi motherboard, and the drive module includes the battery, motor, and motor driver.

2.1. Detection Module
The USB camera is proposed to be used for underwater image recognition of pipe shape, object position and object shape.

A camera module with MIPI/CSI interface can also be used on the Raspberry Pi.

The recognition task for this experiment is more straightforward and requires the shape of the object on the pipe wall to be recognized and the corresponding color warning light to be lit.
At the same time, in order to achieve an accurate forward motion, it is necessary to add to the motor speed control described above a check of the actual direction of the ship's movement, here using the outline of the pipe as a baseline. The camera captures and processes the position of the pipeline outline under the hull at each moment, and through the PID control algorithm, controls the motor differential speed on both sides of the hull to realize the correction of the motion direction.

The specific flow chart is shown in Figure 1.

![Flow chart of detection module.](image)

**Figure 1.** Flow chart of detection module.

### 2.2. Control module

The designed robot is intended to use Raspberry Pi to perform the main control tasks.

Reasons for selection: Raspberry Pi itself integrates more library functions, which are easy to call as well as fast to implement specific functions, and its own computing power is powerful, and its speed can be guaranteed for vision processing. At the same time, the Raspberry Pi is compact and feature-rich, which is suitable for the development of this project.

The proposed GPIO Zero tool library is used to control the motors and the blinking of the LEDs. This library encapsulates common hardware such as LEDs, motors, and various sensors, and allows interaction with them, while retaining the flexibility to allow us to freely control the signals and usage of each port.

The control module wiring schematic is shown below:
As can be seen from Figure 2, AO1 and AO2 are the ports used to output to the first motor, which can be connected to both ends of the motor. AN1 and AN2 are used to control the steering of the motor as well as the operating mode. PWM is used to control the motor speed, and the specific control modes are shown in Table 1 below.

### Table 1. Specific control modes.

| Input | Output | Mode   |
|-------|--------|--------|
| H     | H      | L      | Short brake |
| L     | H      | H      | CCW         |
| H     | L      | H      | Short brake |
| L     | L      | H      | CW          |
| H/L   | H/L    | OFF (High impedance) | Standby |
| H/L   | L      | OFF (High impedance) | Stop |

#### 2.3. Driver module

The proposed TB6612 is used to drive the motor work for the following reasons: high control efficiency, fast heat dissipation and power saving. Its chip introduction is shown in the following figure.
According to the technical index requirements and other related considerations, it is decided to use small size, light weight and long service life of the polymer lithium-ion battery to act as a power source. In the use of lithium-ion batteries need to carry a protection circuit to make it work properly, using micro-USB charging of lithium battery protection circuit. It has two ports with output current of 2.5A, which meets the requirements.

2.4. Motor
The basic working principle of brushless DC motor is to drive the power switching elements of the inverter circuit through the drive circuit with the position signal measured by the rotor position sensor, so that the armature windings are fed in a certain order, thus generating a stepping rotating magnetic field in the air gap and dragging the permanent magnet rotor to rotate. The control logic diagram is shown below:
2.5. Shell
The main consideration of the shell design is its hermeticity. It is proposed to adopt the press-button type and use sealing flange plus sealing bolt fastening at the joints to achieve the sealing of the device outside, and use the waterproof motor to ensure the waterproof safety of the motor part. The three views of the housing are shown in Figure 5.

![Figure 5. Three views of the housing.](image)

3. Overall model display

![Figure 6. Overall design of the device.](image)

The solution is square in overall shape, the main body is 6 motors and a sealed compartment in the middle. The sealed compartment mainly contains the development board, cable power supply device and camera. The material of the sealed compartment is acrylic, so the camera can be fixed downward for pipe inspection below. There are end caps at the front and rear of the chamber to ensure a tight seal. The holes on the end caps with waterproof threading bolts can provide channels for connecting the motor.
to the development board inside the chamber, while the free space in front and rear of the end caps can be used to install modules such as ultrasonic distance sensors and streamline front covers. The sealed compartment is connected to the device shell on both sides with a fixing ring to ensure the stability of the device. Two motors at the front and rear are used for front and rear movement of the thrusters to provide sufficient power output; one motor at each side of the middle is used for lifting and lowering to ensure the overall balance of the device. When steering, the two motors in the diagonal direction rotate in the same direction, which can produce a large torque, so that the device in the rapid production of a right-angle steering. Three views of the device are shown in Figure Group 7

![Three views of the device](image)

Figure 7. Three views of the device.

The current size of the device is 500×380×120 (mm), while the experimental requirement is that it should not exceed 500×400×300 (mm), and there is still space available in the vertical direction. Therefore, mechanical jaws or other removal devices for removing adsorbed materials can be installed in the sealed compartment or on the lower side of the housing, and then controlled by cable connection.

4. Movement mode realization

The robot mainly realizes three kinds of movements: forward, lift and turn. This can be achieved directly by two groups of motors to realize the motion respectively.

(1) Forward - the four motors controlling the forward speed are the same, controlling the speed of the robot forward, and the straightness of the motion trajectory needs to be ensured without considering the error, and the motors on both sides of the hull adjust the speed to ensure the robot's depth position is fixed.

(2) Turning - on the basis of the forward motor state, the four motors realize the robot's turning by means of differential speed.

(3) Lifting--On the basis of the forward motor state, the motors on both sides of the hull adjust the rotational speed, and the PID control algorithm can be used to realize the vertical movement of the robot, which can refer to the flight control algorithm of the UAV. Also use the depth sensor to collect the vertical position of the hull.
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