Inspection Robot for Submarine Pipeline Based on Machine Vision

Fangrui Yin*
Wuhan University of Technology Wuhan, China

*Corresponding author: fangruiyin888@whut.edu.cn

Abstract. In order to improve the intelligence of submarine pipeline inspection, reduce manpower and material resources, and improve inspection efficiency, an underwater pipeline inspection robot based on machine vision is proposed. This paper introduces the existing pipeline inspection methods and technologies, and analyzes the feasibility of pipeline inspection and inspection technologies based on image processing. On the basis of this subject, the corresponding circuit and embedded system are designed, and the related images are sampled, processed and analyzed, and the images are subjected to threshold segmentation, binarization, edge corrosion and other operations. Furthermore, the experimental site and underwater robot were built, and the pipeline defects were detected in real time by using the recognition method based on neural network.

1. Introduction
In recent years, the development of offshore oil and gas resources in the world is very rapid, and the use of offshore oil and gas pipelines is gradually increasing, which is accompanied by the rising risk of economic losses caused by various pipeline defects. Therefore, how to find an effective and low-cost pipeline inspection scheme is a very meaningful research.

At present, most of the external inspection of offshore pipelines adopts the methods of visual photography by divers or external measuring instruments carried by ROV. Divers' price is too high, their life safety is at risk, and their operation scope is limited. Mature products in ROV detection include Magna [2] submarine pipeline detection robot developed by Oceaneering company of America and Discovery [3] submarine pipeline detection robot developed by Tracerco company. The two robots use EMAT electromagnetic ultrasonic transducer and CT computer tomography technology respectively. However, these measures will inevitably produce high costs. In addition, there are some ROV detection methods based on machine vision, such as AURI [4] robot proposed by the cooperation project between PETROBRASS/A, a Brazilian state-owned oil company, and Catholic University of Rio de Janeiro. However, this robot is too large and only suitable for submarine vertical pipelines.

In view of the above background, this paper proposes a pipeline inspection robot based on machine vision, which can realize the localization of defects and autonomous cruise of the robot combined with embedded system.
2. Mechanical structure design
Fig.1 is the overall model diagram of the robot, which is mainly composed of frame, buoyancy block, propeller, battery compartment, equipment compartment, camera and so on.

![Figure 1 Robot Overall Model](image1)

2.1. Robot motion model
The robot adopts six thrusters to cooperate with the movement mode, and can complete floating, diving, rotating, translating and other actions, Figure 2 is a schematic diagram of the robot movement. In the figure, the red arrow is the resultant force (the robot is subjected to the force opposite to the thrust direction), the white arrow is the thrust of each thruster, and the blue arrow is the component force of each thrust in the horizontal and vertical direction.

![Figure 2 Schematic diagram of robot motion stress](image2)

3. Embedded system design
The system adopts stm32f407 as the main control, which controls LED lights, thrusters, etc., and external attitude sensors, pressure sensors, GPS, etc. Automatic pipe inspection can be realized with openmv. The recognition function of the system is mainly realized by jetson nano and csi camera. System block diagram is as follows.
Figure 3 Overall block diagrams of embedded system

3.1. Line patrol module
The image acquisition and processing module of line inspection module adopts openmv, with pixels as high as 30w and built-in various image processing algorithms, which can meet the requirements of pipeline inspection under the changeable underwater environment. Openmv obtains straight intercept and angle through a series of algorithms and sends them to stm32, stm32 performs pid operation and then adjusts pwm wave of propeller. Fig.4 is a picture of the module.

Figure 4 Openmv module

3.2. Communication module
Most communication modes of communication module can't be used underwater, so we choose underwater acoustic communication, which is flexible, convenient, economical and free of cable winding, and can timely transmit the information of power, posture, position and identified foreign objects of the robot to the upper computer, so as to better manage the robot.

Figure 5 Underwater communication modules

3.3. Navigation and Positioning Module
In order to determine the location of pipeline defects, correct positioning information is necessary, The robot adopts Beidou GPS+mpu6050+ms5803 depth sensor, in which GPS and mpu6050 perform attitude fusion to obtain X and Y coordinates, and the depth sensor can obtain depth information after solution. Fig.6 is a schematic diagram of fusion positioning.
4. Software design

4.1. Patrol algorithm
Firstly, the image is thresholded and binarized, then the center point of the image is taken for region growth, and unnecessary information is filtered. Then, the pixels that meet the conditions are fitted by the least square method, and the intercept and angle of the line are obtained. Figure 7(a), (b), (c) and (d) are the straight lines fitted by the least square method, respectively.

![Figure. 7 Line patrol algorithm steps](image)

4.2. Pipeline crack identification
Firstly, the images captured by csi cameras are preprocessed to reduce environmental interference, such as graying, filtering and edge extraction. The specific steps are as follows:

Firstly, the image is grayed out to reduce the interference of environment and background.
Then the image is smoothed and filtered to reduce unnecessary texture interference.
After that, Laplace operator is used for edge detection to extract the information of image edge points. The laplace operator template is selected as follows:

**Table. 1 Mean filter template**

| -1 | -1 | -1 |
|----|----|----|
| -1 | eight | -1 |
| -1 | -1 | -1 |

Finally, the centroid of the area with the largest area in the binary image is selected as the starting point for region growth, and the binary image containing only cracks is obtained. The fracture information can be obtained by sending the image to the trained neural network for recognition. Figure 8 (a), (b), (c) and (d) are the original image, the median filtered image, the Laplace edge detected image and the region grown image, respectively.

**Figure. 8. Defect identification steps**

4.3. *Robot motion control*

The robot control method adopts PID algorithm. PID control algorithm is the most used and mature control algorithm at present. At present, most control loops contain PID algorithm structure. It has the advantages of high reliability, good robustness and simple algorithm, so it is widely used in industrial fields which are sensitive to safety and reliability. Fig.9 is a block diagram of PID control.
Figure 9 PID control block diagram

(1) Patrol control
The line patrol control adopts cascade PID, the inputs are the difference between the line intercept \( \rho \) and the image width and the line slope \( \theta \) (in polar coordinates), and the outputs obtained by PID operation are subtracted, The stm32 adjusts the outputs of four horizontal thrusters according to PID values, Figure 10 (a) and (b) are graphs showing the changes of the line angle (divided by 0.1) and the intercept (the number of pixels separated from the origin) with time.

![PID control block diagram](image)

Figure 10 Defect identification steps

(3) Depth control
In depth control, the input signal is ms5803 depth sensor, and the speed of two propellers responsible for floating and diving is controlled according to the depth information calculated by the sensor.

5. Result analysis
After completing the development of related software and hardware, the robot and related experimental sites were set up, and Figure 11 is an experimental photograph. Through experiments, the robot has stable line inspection and accurate identification.
6. Conclusion
Autonomous cruise algorithm based on machine vision can replace manual operation and reduce the consumption of human resources. When necessary, the operator can choose to switch the manual mode according to the information returned by the robot. At the same time, the use of cameras to identify pipeline cracks can achieve better results and reduce costs to a certain extent. However, the detection algorithm in this paper still has some defects, which will be improved in future work.

References
[1] Zhang Jianbo, Yuan Chaohong, Inspection and maintenance technology of submarine pipeline [J], Petroleum Field Machinery, 2005, 34 (5): 6-10.
[2] ANON. Magna subsea inspection system. [EB/OL] [2016-04-15]. http:// www.oceaneering.com/
[3] ANON. Discovery for subsea pipelines. [EB/OL] [2016-04-15]. http:// www.tracerco.com/
[4] Psarros, Papadimitriou, Chatzakos, et al. FRC: A service robot for subsea flexible risers [C] // International Conference on Advanced Robotics. IEEE, 2010.