Estimating deformation of pipe from its internal image

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Key Words: Image Processing, Infrastructure Inspection, Measurement and Monitoring, Deformation of Pipe

1. Introduction

Sewer pipes are an important infrastructure for environmental protection and sanitary maintenance. However, in recent years, the number of pipes that have exceeded their service life has been increasing. These pipes can cause serious accidents such as road cave-in by their degradation, so regular inspection of the pipes is required. Therefore, the earthworm robot shown in Fig.1 has been developed as a pipe inspection robot [1].

Among sewer pipes, there are rigid pipes such as concrete ones and cast-iron ones, and flexible ones such as vinyl chloride ones. Each pipe has different types of degradation. In particular, a flexible pipe made of vinyl chloride shows its unique degradation, such as flattening.

In this paper, we propose a method of estimating oblateness of a pipe from its internal image captured by an earthworm robot. Covariance matrix of the image is used to obtain oblateness.

Fig.1: Earthworm Robot

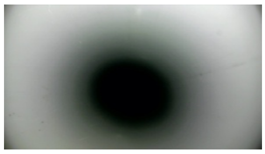
2. Proposed Method

2.1 Outline of the proposed method

When an image is taken inside a pipe, the pipe is illuminated by a light on the head of the robot, so the intensity of the image is in inverse proportion to the distance from the robot. Since the dark region of the image looks like an ellipse by deformation of a pipe, we find the axial directions and the axes length of the ellipse by calculating the eigenvectors and eigenvalues of the covariance matrix. From each axis length, we calculate the oblateness of a pipe.

2.2 Image Preprocessing

As a method of obtaining the axial directions and axes length of the ellipse, we calculate the weighted mean vector and covariance matrix with the intensity values of the image as the weight. Here, the extracted region is dark in the original image shown in Fig.2 (a), so we convert the original image to a grayscale image and apply negative-positive inversion to the image. In addition, in order to increase the weight of the extracted elliptical region, we set a threshold of the intensity and measure only the region above the threshold (Fig.2 (b)). Furthermore, if there is dirt in the pipe, we remove it from the image using noise removal processing.



(a) Original Image

(b) Image with inversion and thresholding

Fig.2: Pipe Image.

2.3 Calculation of the axial directions and the axes length of the ellipse

Let N be the total number of pixels in the image, a feature vector that has coordinate data is $\boldsymbol{x}_n = (i_n, j_n)^T$, n=1,2,...,N. Let $f(i_n, j_n)$ be the intensity of each pixel, total intensity F of the entire image is represented as

$$F=\sum_{n=1}^{N} f(i_n, j_n)\,. \tag{1}$$

The weighted mean vector $\boldsymbol{M}$ is represented as

$$\boldsymbol{M}=\frac{1}{F}\sum_{n=1}^{N} f(i_n, j_n)\boldsymbol{x}_n. \tag{2}$$

Furthermore, the covariance matrix $\boldsymbol{S}$ is represented as

$$\boldsymbol{S}=\frac{1}{F}\sum_{n=1}^{N} f(i_n, j_n)(\boldsymbol{x}_n\text{-}\boldsymbol{M})(\boldsymbol{x}_n\text{-}\boldsymbol{M})^T. \tag{3}$$

The mean vector $\boldsymbol{M}$ (2) corresponds to the center coordinates of the ellipse. The axial directions and the axes length are obtained by calculating the eigenvectors and eigenvalues of covariance matrix $\boldsymbol{S}$ (3). Let a and b respectively be the semi-major and semi-minor axis length of the ellipse, oblateness h is calculated by

$$h=1\text{-}\frac{b}{a}. \tag{4}$$

3. Creation of experimental data

It is difficult to physically measure the degree of oblatening in a sewer pipe that is actually used. Thus, in this study, we imitate a flattened pipe by deforming a regular pipe.

We use a PVC pipe and apply uniformly distributed load on it to deform the pipe as shown in Fig.3. Table 1 shows the obtained data.

In this experiment, we used a monocular camera (f = 2.1 mm, D = 122°, H = 99.5°, V = 78.8°).

Table 1 Diameter and oblateness of PVC pipe

Numbers	1	2	3	4	5	6	7
Vertical Diameter[mm]	114	114	109	107	103	100	97.6
Transverse Diameter[mm]	114	116	119	121	123	124	126
Oblateness	0	0.020	0.086	0.116	0.157	0.196	0.225

Fig.3: Deformation process of a pipe.

4. Experiments

4.1 Experiment Outline

We confirm the effectiveness of the proposed method by using the oblateness from Table 1 as true value and comparing it with the oblateness that is estimated from the image. We set the threshold of intensity mentioned in section 2.2 to 1.

4.2 Experimental Results

Fig.4 shows a graph comparing true and estimated values of the oblateness. Fig.5 shows images of the inside of the pipe with the extracted axis of the ellipse and images with inversion thresholding.

In Fig.4, true and estimated values of the oblateness are relatively close to each other indicating that the estimation is correct. The estimated oblateness is larger than the true value. This may be because the aspect ratio of the image taken inside the pipe is not 1:1 and the head of the robot is tilted up and down. In Fig.5, it can be seen that the axial directions are estimated almost accurately.

In this experiment, the oblateness and the axial directions were determined using the image inside the vinyl chloride pipe. It was confirmed that oblateness and axial directions could be estimated almost accurately. However, it was found to be difficult to accurately estimate the minute deformation of the pipe because estimated oblateness varies.

Fig.4: Comparison between estimated and true values of oblateness with PVC pipe images

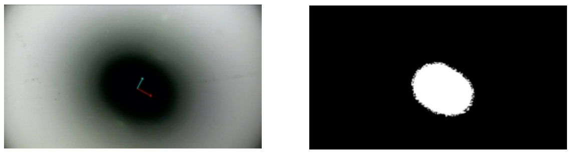
(a) Image 1

(b) Image 2

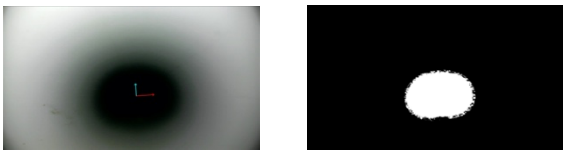
(c) Image 3

(d) Image 4

(e) Image 5



(f) Image 6



(g) Image 7

Fig.5: Left: original image and extracted axes (blue: semi-major axis, red: semi-minor axis). Right: thresholding.

5. Conclusion

In this paper, we proposed a method of estimating deformation of a pipe from its internal image using covariance matrix. We estimated deformation amount by obtaining the axial directions and the axes length of the ellipse from the eigenvectors and eigenvalues of covariance matrix and calculating the oblateness. We conducted the experiment using images taken inside a deformed vinyl chloride pipe, and effectiveness of this method was confirmed.

This research was partially funded by Sewerage Applied Research Project of the Ministry of Land, Infrastructure, Transport and Tourism.

REFERENCES

[1] Ryutaro Ishikawa, Takeru Tomita, Yasuyuki Yamada, Taro Nakamura, “Investigation of Odometry Method of Pipe Line Shape by Peristaltic Crawling Robot Combined with Inner Sensor,” in Proceedings of 2017 IEEE International Conference on Advanced Intelligent Mechatronics, pp.1275-1279, 2017.