AI image analysis technologies for efficient water pipeline inspection

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ABSTRACT

Inspection of water pipelines with cameras under pressure is attracting attention. The inspection can be performed without digging the ground and water interruption by inserting a camera into aging water pipes while the water is flowing. However, the inspection has two problems: (1) a long-time visual check by expert engineers is required and (2) variations in the evaluation standards. To solve these problems, we have developed an AI image analysis system for automatically judging the state of degradation of water pipelines by using images captured from the in-pipe endoscope cameras. This report describes the developed technology and software to support the inspection work.

1. INTRODUCTION

In Japan, the number of aged water pipelines over 50 years old is increasing. These aged pipes often cause water quality and water leakage accidents. Therefore, inspection and investigation of pipeline facilities are required for preventive maintenance in recent years.

In recent years, as reported by Kawamura, Arai, Koizumi, Inakazu, Yokokawa, Kaji, Suzuki, Ariyohsi, and Moriyama (2017) and Kunizane, Koizumi, Arai, and Yamamoto (2018), attention has focused on uninterrupted water camera surveys used to inspect underground water pipelines. These surveys are conducted by inserting an endoscope camera into pipes through fire hydrants or air valves without digging the ground and water interruption.

However, since it is necessary for an expert engineer to check various images for a long period of time, reducing the workload and controlling the variation in evaluation standard have emerged as important issues.

Therefore, we developed a technology to automatically judging the state of degradation of water pipelines by utilizing AI image analysis technology to images of the inside pipes captured from the in-pipe endoscope cameras. Details of the developed technology and inspection support software are described below.

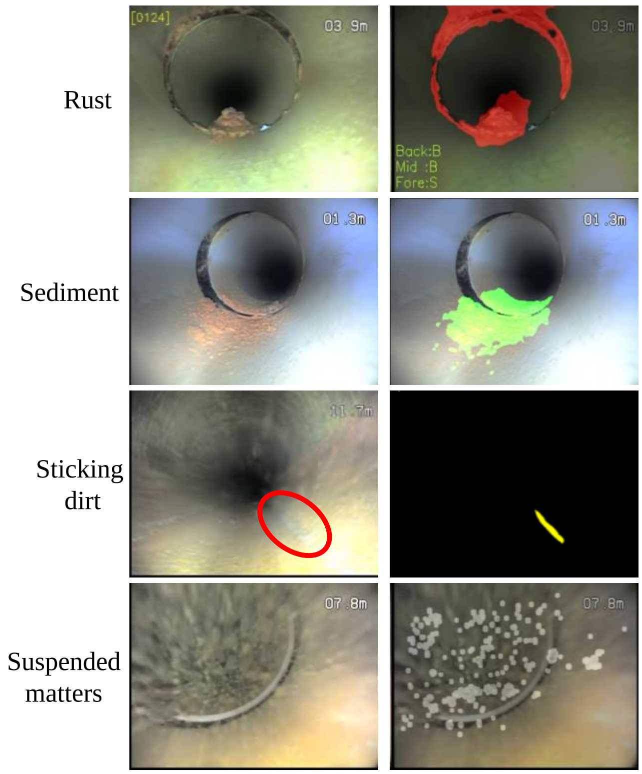
2. AI IMAGE ANALYSIS TECHNOLOGIES FOR WATER PIPELINE INSPECTION

In developing AI image analysis technology to images of the inside pipes, we selected representative survey images of various anomaly categories and deterioration ranks. Based on these images, technical studies were conducted according to these items (rust condition, sediment, sticking dirt and suspended matters) specified in the guidelines (Japan Water Endoscope Camera Association (2020)).

In the following, we describe the detection of abnormal areas, evaluation of deterioration ranks, and the process of judgment corresponding to camera motions.

2.1. Detection of anomaly areas

First, using AI-based pixel-by-pixel segmentation and edge detection, the system detects anomaly areas in images captured by in-pipe endoscope camera. Figure 1 shows examples of the detection results of “rust”, “sediment”, “sticking dirt”, and “suspended matters” caused by pipe deterioration. The figures on the left show the input images and the right show the detection results.



a) Input image b) Detection result

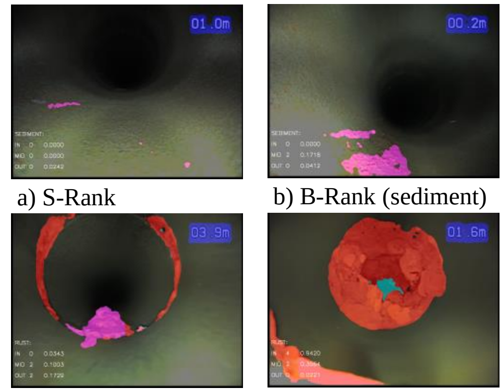
Figure 1. Anomaly detection results

2.2. Judgment of deterioration rank

As mentioned earlier, a deterioration rank is evaluated based on the diagnostic evaluation standard defined in the guidelines (Japan Water Endoscope Camera Association (2020)). Each item is ranked in the order of S, A, B, C and D, where S denotes the healthy state and D denotes the worst state. These evaluations are based on the size and location of the abnormal area and the structure of the pipeline. Figure 2 a) shows an example of an S-rank image without deterioration, b) shows a B-rank image of a sediment, and c) and d) show examples judged as B and D-rank images of rust.

The blockage rate due to rust on the inner surface of the pipe is cited as one of the evaluation indicators, and this is used to judge the rank of deterioration. The blockage ratio is calculated from the percentage of the detected rust area occupied from the inspection area in the image. The inspection area is pre-specified according to the structure of the pipe. Based on the guidelines, if rust is detected and the blockage rate is less than 30%, it is rank B. On the other hand, if the blockage rate is more than 30%, it is rank D.

As another evaluation index, the occupancy rate is used to judge the deterioration rank of sediment. The occupancy rate is calculated from the percentage of the detected



a) S-Rank b) B-Rank (sediment)

c) B-Rank(Rust) d) D-Rank (Rust)

Figure 2. Rank judgement result

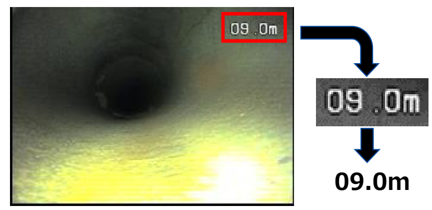


Figure 3. Recognize the numbers indicating the camera's position with OCR

sediment area in the bottom of the water pipe. If the occupancy rate of sediment area is less than 30%, it is rank B. On the other hand, if more than 30% of the sediment is detected, it is rank D.

2.3. Judgment process corresponding to camera motion

It is very difficult to inspect the inside of water pipes without water interruption. One of the unique challenges is the problem of sediments, suspended matters and other impurities in the water moving due to water flow and camera motion. To solve this problem, we propose a method to switch the detection target corresponding to the motion and direction of the camera.

Basically, the system uses images when the camera is moving forward, because when the camera is pulled back, deposited sediments, adhesion materials and other impurities are diffused and appear in images more easily. However, in the case of detecting sticking dirt on the pipe inner face, the system uses images when the camera is moving backward to detect the traces (as shown in circle in Figure 1) made by the camera scraping off the pipe inner coating.

Since sediments are diffused when moving the camera backward, it is expected to improve accuracy of sediment detection by using images captured not only when the camera is forward but also when it is backward.

For suspended matters, the accuracy of judgment can be improved not only by using images captured when the camera is forward, which is less affected by sediments, but also by selecting images captured at the time when the camera is stopped.

These processes can be realized as follows.

1. Recognize numerical values in an image using OCR as shown in Figure 3 (Numerical values indicating the cable length of the camera, that is, the position of the camera)
2. Judge camera motion (moving/stopped) based on the quantity of change in a sequence of images
3. Set the maximum value recognized by OCR and the point where the image is stationary as the turning point (Figure 4).
4. Set the frames before the turning point as forward and these frames after as backward. After that detect each anomaly area and judge its deterioration rank corresponding to Table **1**.

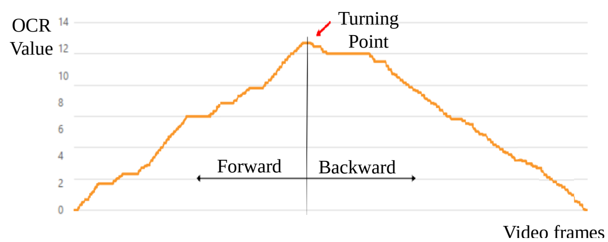


Figure 4. Judge camera motion with OCR

Table 1. Inspection target corresponding to camera motion

item	Forward / Backward
Sediment	Forward and backward
Sticking dirt	Backward
Suspended matters	Forward / Stop
Rust and others	Forward

2.4. Experimental Results

We selected 116 rust images and 142 sediment images with relatively clear detection targets from the three ranks of S, B, and D, which are easy to judge the deterioration ranks. Some of the evaluation images are shown in Figure 2. Experiments were conducted using these images with the proposed method to detect abnormal areas and judge the deterioration ranks.

First, we describe the experimental results of detecting anomalous areas. The rust blockage rates calculated from ground truths are indicated by black circle marks, and those

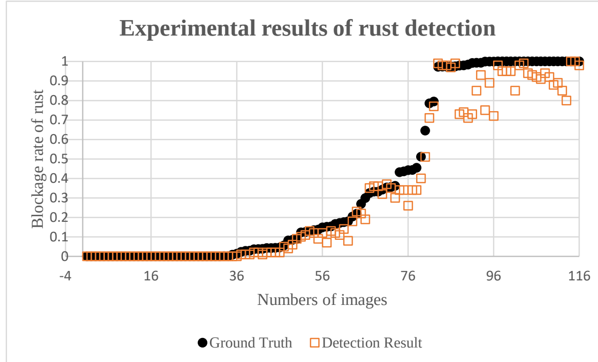


Figure 5. Experimental results of rust detection

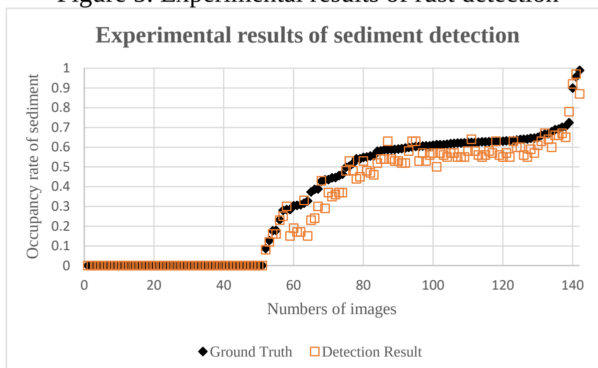


Figure 6. Experimental results of sediment detection

calculated from the proposed method are indicated by square marks in Figure 5. Experimental results show that the rust blockage rates calculated from the proposed method are close to those calculated from ground truths.

The same method was conducted on the sediment occupancy rate, and the results are shown in Figure 6. The figure shows that the occupancy rates of the sediments calculated from the proposed method are close to those calculated from ground truth.

Next, we describe the experimental results for judging the deterioration rank of images. Table 2 and Table 3 show the results of rust images and sediment images detection of S/B/D ranks as described earlier, respectively. The horizontal axis of the table indicates ground truth, the vertical axis indicates prediction results, and the diagonal cells indicate the number of correct images.

The experimental results for the degradation ranks show that the accuracy rates for the rust and sediment ranks were 96.6% (113 of 116 images were correct) and 94.4% (134 of 142 images were correct), respectively. We obtained good results with these images used in the evaluation.

Based on the results of the experiments described above, for both rust and sediment, there were no cases where ground truth of rank S was misjudged as rank D with a large rank error.

Table 2. Rank judgement results: rusk

Rank judgement results: rusk		Ground truths		
		S	B	D
prediction results	S	50	0	0
	B	2	26	0
	D	0	1	37

Table 3. Rank judgement results: sediment

Rank judgement results: sediment		Ground truths		
		S	B	D
prediction results	S	52	0	0
	B	0	6	1
	D	0	7	76

Also, there were no cases where ground truth of rank D was misjudged as rank S. We confirmed that the misjudgment of ranks S and B occurred near the predefined thresholds. Misjudgments of ranks B and D were caused by the same factors. More evaluation images will be added in the future.

3. SOFTWARE TO SUPPORT THE INSPECTION WORK

To support the water pipeline inspection, we developed a software to efficiently check the results of AI image analysis. The combination of AI image analysis technology and this software is expected to have three effects. Firstly, it is not necessary to check all the images in detail. Thus, the efficiency of inspection work can be improved. Secondly, it is possible to avoid missing the detection of deteriorated areas by focusing on areas where the AI indicates risk of deterioration. Finally, it is also expected to reduce the variation in evaluation standard among expert engineers.

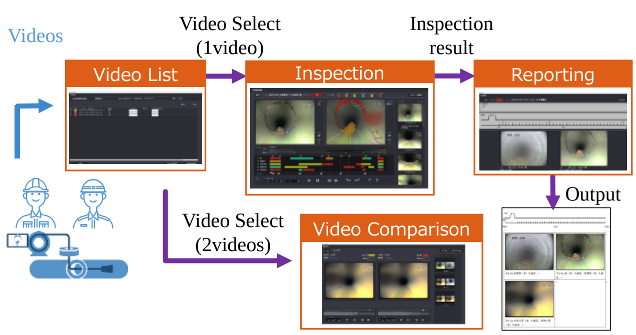


Figure 7. Software overview

3.1. Software Overview

Figure 7 shows an overview of this software, including window switches. The software consists of four main windows, each windows has the following functions.

・Inspection Window: GUI for efficiently checking AI deterioration judgment results

・Reporting Window: Output representative images and deteriorated areas in report format

・Video Comparison Window: Two images can be compared for visibility

3.2. Software features

The functions of the four windows contained in this software are described below.

1) Video List Window

The system manages multiple video files as a list and provides searching functions using information from water pipelines (Figure 8). When a video file is selected on this window, it is possible to open Inspection Window and Video Comparison Window.

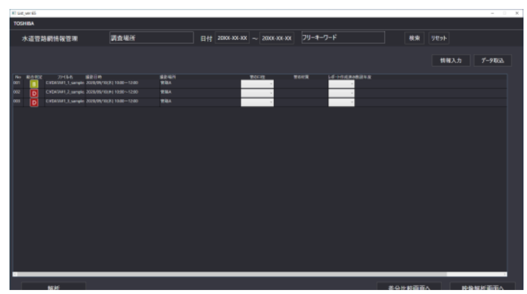


Figure 8. Video list window

2) Inspection Window

Inspection window (Figure 9) has the function of displaying the images taken on-site and the AI image analysis results side-by-side, displaying the deterioration areas and deterioration status, and it is possible to effectively identify highly deteriorated areas from these input images. The expert engineer inspecting the water pipeline can check this information and select a typical deterioration image as a snapshot, which can also be used to prepare an investigation report in the reporting window.

3) Reporting Window

By selecting a representative image of a deteriorated area by checking it in the Inspection Window, a report can be generated includes the position of the camera corresponding to these selected images and the AI image analysis results of the water pipelines. The system automatically outputs standardized text following the report format and has the function to edit it. It is also possible to output the report in Microsoft Word (docx) format (Figure 10).

4) Video Comparison Window

When two video files are selected in the Video List window, the system displays the two video images side by side (Figure 11). It is possible to compare new and deteriorated conditions of the same pipe, before and after cleaning, etc.

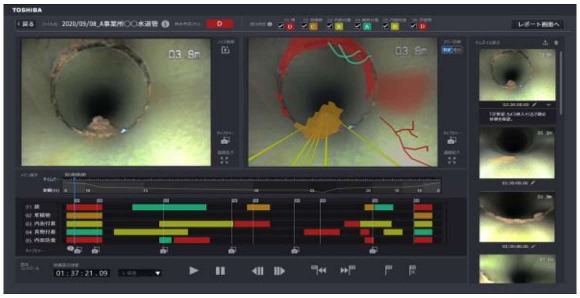


Figure 9. Inspection window

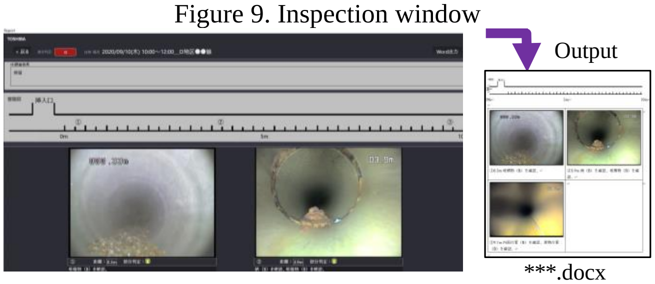


Figure 10. Reporting window

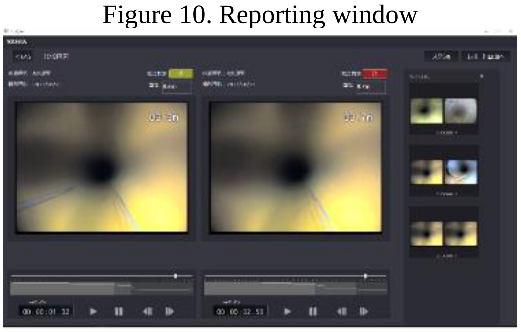


Figure 11. Video comparison window.

4. Conclusion

In this study, we proposed a technology for automatically judging the state of degradation of water pipelines and software to support the inspection work. In the future study, we will continue to verify and improve the technology using more images captured from in-pipe endoscope cameras and intend to put the technology to practical use and contribute to the maintenance and management of water pipelines.

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