The Fifteenth International Symposium on Artificial Life and Robotics 2010 (AROB 15th '10),
B-Con Plaza, Beppu,Oita, Japan, February 4-6, 2010

Real-time Generation of Developed View for Drain Pipe Based on Web Camera Video

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Abstract: A real-time algorithm for generating the interior developed view of a drain pipe based on video taken by a robot-inspector is presented. The objective is to increase the efficiency of examination and maintenance of a drain pipe, and make it possible to check the situation of the drain pipe with an easy view. The key idea of the paper is to identify the central point of the drain pipe automatically based on the video image and connect the images as a development map of the drain pipe in real time. We described the Hough transform method and the Least-Squares method for searching the centre of the drain pipe in detail.

Keywords: drain pipe, developed view, inspection system, real-time algorithm**.**

I. INTRODUCTION

With the increasing of the number of the drain pipes which have been over their lifetimes, the drain pipes are getting decrepit. On the other hand, the requirements of rebuilding the drain pipes and the laying of optical fiber in the sewer pipes are increasing. So in order to grasp the situation of the drain pipe exactly, the examination of the drain pipes is being more and more important.

In Japan, from 1982, we have used robot-inspectors with video cameras instead of human beings for small-bore drain pipes that we can not enter directly. Furthermore, in order to make the situation in the drain pipes to be easier to understand visually, systems which can generate the developed view of drain pipes have been produced and been put into practical use up to now.

But systems being used now usually create the unfolded view after the examination for the reason of time consuming. Because of this problem, we can not confirm the situation of the drain pipes during the investigation.

We are currently developing a remote system, designed to generate the developed map of a drain pipe in real-time and be advantaged of locating the center point of the pipe. The algorithm we presented this time use the computer vision library OpenCV and can automatically identify the centre points of different types of drain pipes. Therefore, it will be possible for us to check and record the developed view of the drain pipes during the investigation, and the accuracy and efficiency will be significantly improved. As a further purpose, we plan to develop an auto visual inspection system to recognize the defects based on this algorithm together will some auto detection algorithms.

In this paper, first we introduce the wireless inspection robot we used in our research briefly and describe the unfolding algorithm and the centre identification algorithm in detail. The real data taken by our robot will be introduced and used during the explanation.

II. HARDWARE ENVIRONMENT

The inspection robot we used in this research is developed together with the Technical Solutions Company ISHIKAWA IRON WORKS, shows in Fig.1.

Fig.1. Structure of the inspection robot

The robot has the following specifications.

Table 1: Specifications of robot

Speed	:	13.7m per minute
Camera	:	44 mega pixels CCD
Drive system	:	Double motors eight-shaped crawlers
Power supply	:	Two 7.2 Volt batteries
Pipe diameter	:	200mm
Size	:	L355mm×W155mm× H150mm / 5.4Kg

Comparing with former inspection robots, the most significant feature is that it carries with wireless device. For that we can control and get the drain pipe image in the ground using a terminal computer instead of using cables like the former ones. This also makes it possible for us to do some processes for the real-time videos gotten through the wireless device.

In addition, we are also trying to improve this robot with other equipments to recognize defects. For example, a set of rotating detection arms is under studying now.

III. UNFOLDING ALGORITHM

Unfolding algorithm is the process to generate the developed view (also unfolded view) of the drain pipe. In order to make the developed map, the following processes should be executed, refer to Fig.2.

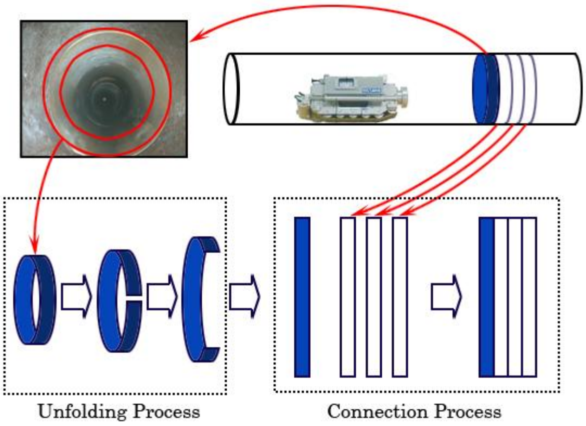

Fig.2. Processes for developed view

(a) Unfolding process: open out the circle image and lay it flat to a band one.
(b) Connection process: connect the unfolded images together from several frames to generate a developed map of the drain pipe.

Here we first introduce the unfolding algorithm.

It is easy for us to do this using the interpolation when we know the coordinate transformation between the original image and the unfolded one. Considering the process speed, here we use the bilinear interpolation to finish this work. The bilinear interpolation uses the nearly four pixels to estimate the object position.

We can see that the original image is the polar form of the unfolded image. So using the polar transformation based on a certain central point with some other calculations, we can get the coordinate relationship between them. It shows that the central point we used in the unfolding process is very important to assure the quality of the developed image. When the central point we used in the process is deviated from that of the drain pipe, the developed image will be distorted. For instance, the pipe-joint of the drain pipe will be a straight line in the developed image when we use the centre of the pipe. If the central point has been deviated, the pipe-joint will be a curve.

On the other hand, it is inevitable for the robot-inspector to have some shake due to the rough and uneven in surface which will cause the offset of the web camera and change the position of the central point of the drain pipe in the video image. For this reason, it is necessary for us to find the centre of the pipe from the image automatically.

In our algorithm, we use the combination of following two methods to finish this work.

IV. HOUGH TRANSFORM METHOD

The pipe-joints of the drain pipe can be obviously seen caused by the reflection of the light. Usually, the pipe-joints are almost of circular forms. So if we treat them as circles, we can use Hough transform to recognize them. Fig.3 shows the results by Hough transform we used in our algorithm.

Fig.3. Pipe-joints and Hough transform results

Hough transform is a feature extraction technique used in image analysis to find features of a shape in an image by voting procedure. In theory, the general Hough transform can be used on any kind of shapes, although the complexity of the transformation increase with the number of parameters needed to describe the shape. In practice, it is only generally used for finding straight lines or circles.

The Hough transform can be described as a transformation of a point in the x,y-plane to the parameter space. The parameter space is defined according to the shape of the object. For example, a circle can be described in the x,y-plane by:

$$r^2 = (x-a)^2 + (y-b)^2 \qquad (1)$$

Where a and b are the center of the circle in the x and y direction respectively and where r is the radius.

The parameter space can now be spanned by (a, b, r). For each point on the desired circle, if we draw a circle with center in this point with the desired radius (For facilitate description, we suppose we know the radius while in fact we do not.), all the circles will pass through the center of the desired circle. If we use an accumulator to count all coordinates that the perimeter of the circles we drawn pass through, the maximum value will be the center we desired. When we do not know the radius, it is the same just change a 2-dimensional accumulator to a 3-dimensional one.

1. Pre-processing for Hough Transform

Although pipe-joints can present good objects for image processing, the video pictures were recorded under very difficult conditions, and there are three disadvantages inherent in these pipe-joint images:

- Low and uneven contrast around the pipe-joints due to poor illumination;
- A very dirty background owing to corrosion;
- A big gap because of residual effluent.

These features make it difficult to detect the pipe-joint boundaries. For this reason, we do the following pre-processing in our algorithm to increase the detection accuracy of the result.

(a) Gray-scale transformation
(b) Edge detection
(c) Dilatation and blurring

We do the gray-scale transformation to reduce the calculation amount, the edge detection process to find the edge of the pipe-joint and the dilatation and blurring to make the pipe-joint more visible and evident.

The advantage of Hough transform method is it can give an accuracy estimate of the central point although the pipe-joint is incomplete and with some noises. But for images without pipe-joints or the pipe-joints are unobvious, the Hough transform will be not applicable.

V. IMPROVED LEAST-SQUARES METHOD

Usually, the centers of the drain pipes are the darkest part in the pictures. The improved least-squares method is the method which we use the gray-scale data to find the minimum points of the x and y coordinates by least-squares method and to determine the central point.

By experiment, we find use a second degree curve (a parabola) to approximate the given set of data directly[2] can not give a satisfactory result. Therefore, we think of two improvements for this method in our algorithm.

The first improvement is to use a higher degree polynomial to approximate the given data set. Considering the computational complexity and consuming time, we use the least-squares 4^{th} degree polynomials to approximate the given set of gray-scale data in our research.

Another improvement introduced in our algorithm is using a variable scale of data set to perform the least-squares fitting. As for the influence by the lighting or the noises in the background of the image, the fitting result shows not very well. So we loop the fitting process with a new scale according to the darkest point found in the previous time. By experiment we found two cycles of the process can already give a satisfactory result for the centre estimation and do not cost much computation times. One example shows in Fig.4.

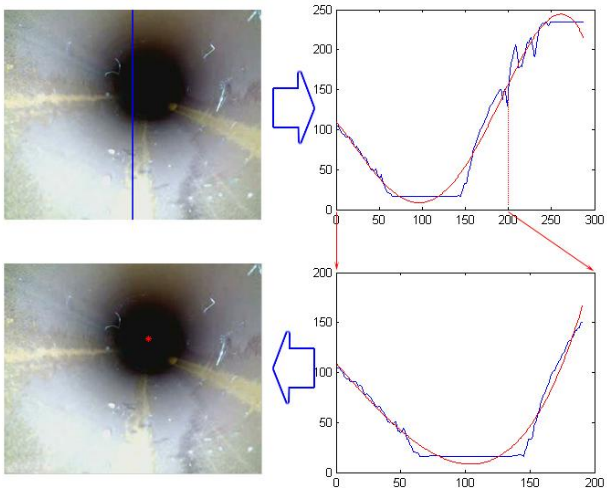

Fig.4. Improved least-squares method

The advantage of this method is it can be used in almost all kinds of drain pipes. But when the drain pipe is not very straight, the darkest point of the image may be different with the centre point of the drain pipe.

Considering the advantage and disadvantage of this two method, we apply the combination of them in our algorithm.

VI. CONNECTION

After getting the unfolded images of separate frames, we need to connect them to a developed map of the drain pipe. Usually, the splicing effect is affect by the speed of the robot-inspector, the diameter of the pipe, the width of the folded band image and the interval of the frames for which we do the unfolding process. It is difficult to determine a relationship of all these factors. But actually, the speed of the robot and the diameter of the drain pipe are constant, and the intervals of the frames can be determined by the real-time constraint. (As the more frequent we grab the frame for processing, the less processing time we will have to satisfy the real-time requirement.) We just need to determine the width of the folded band to finish the connection process.

Here, by experiment, with the speed of 13.7m per minute, the diameter of 200mm and the intervals of every three frames (we will discuss it later), a 5 pixels width of the folded band image can provide a better result. An example is given in Fig.5.

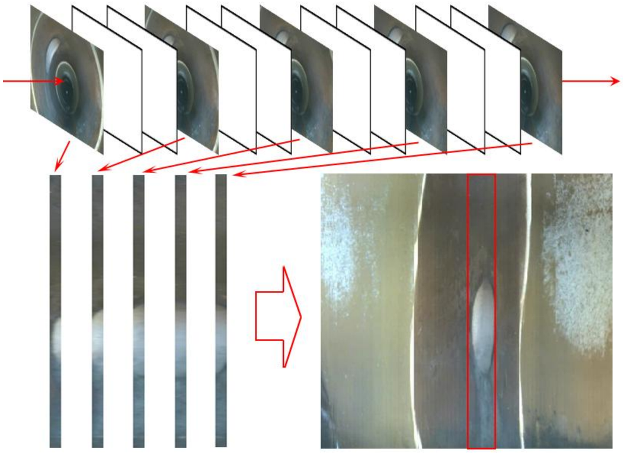

Fig.5. Example of connection

One problem here is that according to the different situation in the drain pipe, the identified central point maybe sometimes with a certain error. This will cause the developed map not be continuous. So in our algorithm, we check the deviation of the current central point with the previous one, and discard ones with too large deviations.

Then, let's discuss the real-time constraints. The following table shows the processing time's for our algorithm.

Table 2: Processing time

Operation environment	
CPU	2.10GHz × 2
Memory	1.00GB
Language	C++
Running time (per frame)	Hough*/LS**
Finding center	43.8ms / 17.1ms
Unfolding	28.1ms
Connection	1.5ms
All	73.5ms / 46.7ms

*Hough: Hough transform method

**LS: Improved Least-Squares method

For the video, usually it has the frame rate of 30fps (frame per second). One frame costs 33.3ms and three frames cost 100ms. As the process for one frame in our algorithm mostly cost 73.5ms, less than three frames' time, it is possible for our algorithm to be used in real-time process.

VII. CONCLUSION

In this paper, we have introduced an algorithm for generating the developed map of the drain pipe. The advantages of our algorithm are mainly in two parts.

First, it can identify the central point of the drain pipe automatically and accurately, by using the combination of Hough transform and Improved Least-Squares methods.

Second, it can be used in real-time detection, which makes it possible to confirm the situation of the drain pipes during the investigation.

One possible problem is that when the running situation of the drain pipe is so bad and makes the robot shake seriously, the connection result will be bad due to the rock of the video image.

As for the further research, based on this algorithm, we plan to develop an auto visual inspection system to recognize the defects together will some auto detection algorithms or some additional detectors. For example, by our algorithm, the pipe-joint will be near a straight line and be easier to be excepted from the defects than do it directly using the original video image.

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