The Thirteenth International Symposium on Artificial Life and Robotics 2008(AROB 13th '08),
B-Con Plaza, Beppu, Oita, Japan, January 31-February 2, 2008

Three Dimension Scanner of a Pipe with Tilt Detection

K. Kawasue[1], S. Sakai[1], T. Wakiyama[1], S. Oyama[2] and M. Senda[3]

1. University of Miyazaki, 1-1 Gakuen Kibanadai-nishi, Miyazaki, 889-2192 JAPAN
(Tel : 81-0985-58-7583; Fax : 81-0985-58-7583)
(kawasue@cc.miyazaki-u.ac.jp)
2. B_mount Products
3. Obayashi Road

Abstract: The 3D quantitative measurement system for a sewer pipe is introduced. Two parallel lasers are rotated by the motor and draw the two annular streaks on the inside surface of the pipe. The circular laser streaks are recorded by the CCD camera. The measurement of the cross-section is established by analyzing the recorded streaks. The tilt of the robot against the axis of the pipe is detected by the deviation between two parallel lasers. It enables us to measure the vertical cross section of the pipe regardless the tilt of the system to the pipe. Experimental result shows the feasibility of the system.

Keywords: Sewer, Pipe measurement, Calibration, Image processing, Three dimension Scanner

I. Introduction

Sewer pipes over 380,000 kilometers in total are existed under the ground in Japan. However, worn pipes have been increased and a number of subsidence of a ground caused by the collapse were occurred. Since 80 percent of these pipes have a size of 450 mm or less in diameter, human inspector can not enter into these pipes by himself. Recently, the inspection of the pipe is executed by the moving cart with CCD camera. Currently human inspector judges the condition of the pipe by the images recorded by the CCD camera. It should be noted that the judgment by the human causes the individual variation since it depends on the person's sense. Quantitative measurement is required.

In order to cope with this problem, we have developed the robot equipped with two parallel lasers and CCD camera. The circular laser streaks that appeared on the inside surface of the pipe display the shape of the pipe. Since the angle of the system against the axis of the pipe is appeared as the deviation of the two circular streaks, the measurement of the vertical cross section of the pipe is executed regardless the tilt of the system to the pipe.
Quantitative and quickness measurement can be realized using the developed system.

II. Measurement System

Fig.1 shows the measurement system. Fig.2 shows the photograph of the measurement robot. The robot equipped with two parallel laser projector and these lasers are rotated in circumferential direction. CCD camera runs along the inside of the sewer pipe and measures the shape of the pipe by analyzing the laser streaks appeared on the inside surface of the pipe.

Fig.3 shows the parallel laser projector equipped on the robot. The laser is passed along the center of the non-shaft motor and is divided at beam-splitter. One goes straight and is refracted by the mirror that is set at the edge of the motor. The other goes to the normal direction against the axis of the motor by being refracted at the beam-splitter. Therefore, the two parallel lasers with 180 degree phase difference are projected in the normal direction from the axis of the motor. The lasers are rotated by the motor and draw the two annular streaks on the inside surface of the pipe.

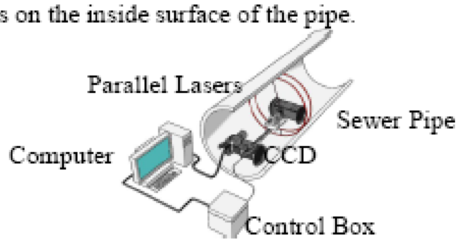


Fig.1 Measurement system

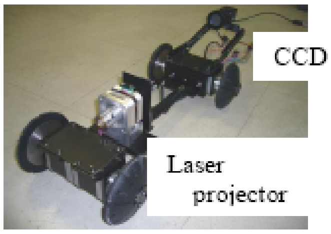


Fig.2 Robot for measurement

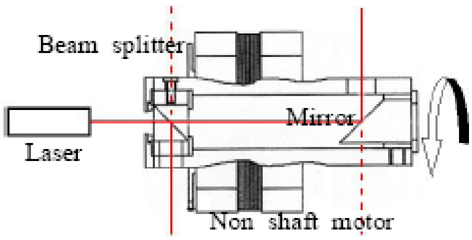


Fig.3 Laser projection system

The image recorded by the CCD is digitized through IEEE1394 interface and processed by the computer. Since the rotation of the motor is 15 r/s and the exposure time of the CCD is 1/30 s, the laser draws a half circular streak in an exposure time as Fig.4. These two half circular streaks can be separated by detecting the start angle of the each streak. The start angle of the each streak can be detected easily by use of the z phase signal from the motor and the vertical sync signal of the CCD camera. The whole circular streak can be composed by two separated half streaks between two consecutive field images from the CCD camera. The measurement of the cross-section is established by analyzing the whole circular streaks.

The shape of the streak is varied depend on the surface condition and deformation of the pipe.

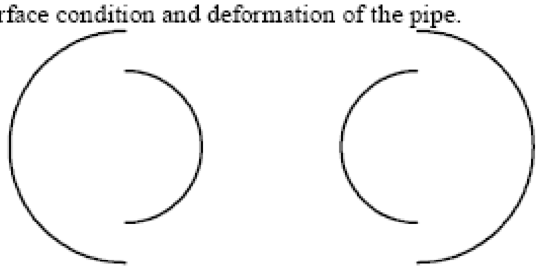
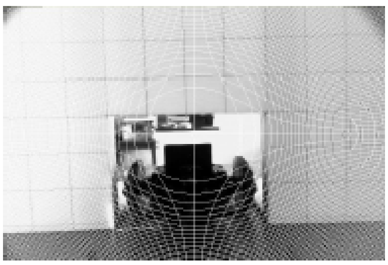


Fig.4 Detection of streak using phase difference

a. Original image



b. After correction

Fig.5 Correction of the camera distortion

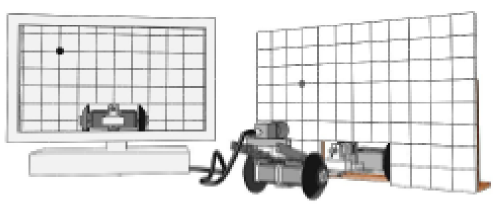


Fig.6 Calibration setup

III. Calibration

1. Correction of camera lens distortion

The calibration is an important task to realize the quantitative measurement. In order to calculate the quantitative data from image, following calibration procedure is executed.

The size of the pipe usually has a range from 200mm to 600mm, the wide lens is required to meet with the range of the pipe. Since the general wide lens has a distortion, the distortion should be corrected on a preprocessing. The relation between original camera coordinates and undistorted coordinates is defined by method [4] as the following function.

$$\begin{cases} u' = k_1(1 + k_2(u^2 + v^2))u \\ v' = k_1(1 + k_2(u^2 + v^2))v \end{cases} \quad (1)$$

where, (u,v) is an original camera coordinates and the (u',v') is an undistorted camera coordinates. These coordinates have an origin at the center of the image. The image can be corrected as Fig.5 by finding the adequate parameter (k_1,k_2).

2. Calibration

The calibration setup is shown in Fig.6. The scale board is set as matching with the laser slit plane position. The image of the scale board is recorded by the CCD and is used to determine the calibration parameters. The relation between the camera coordinates (u,v) of the CCD and the world coordinates (x,y) of the scale board is as follows.

$$s\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad (2)$$

where, k_{11}-k_{32} are parameters that consider the rotation, scale and displacement between camera coordinates and world coordinates. These parameters are determined by feeding some corresponding positions between camera coordinates and world coordinates. The feeding is executed by use of the mouse device for the camera coordinates and keyboard for the corresponding world coordinates. k_{11}-k_{32} are determined by feeding over 4 corresponding points to (2). After all, the function for converting from the camera coordinates to the world coordinates is as follows.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} k_{31}u - k_{11} & k_{32}u - k_{12} \\ k_{31}v - k_{21} & k_{32}v - k_{22} \end{bmatrix}^{-1} \begin{bmatrix} k_{13} - u \\ k_{23} - v \end{bmatrix} \quad (3)$$

All points on the circular laser streak are converted to the world coordinates and the cross sectional shape of the pipe is estimated.

The whole shape of the pipe is reconstructed by integrating the cross section of the pipe along the axis of the pipe. Since the robot is droved by a pulse-motor, the droved distance can be estimated by the number of pulses sent to the pulse-motor.

IV. Detection of the tilt of the robot against the axis of the pipe

Generally, the cross-section of the pipe should be measured vertically against the axis of the pipe.

In a practical case, there is a possibility that the robot is inclined against the axis of the pipe by the bad condition of the pipe. Fig.7 shows the schematic of the relation between an inclined robot and two parallel lasers. The angle of the robot against the axis of the pipe is detected using the deviation between two parallel lasers. When the robot is inclined against the pipe, two deviated ellipse streaks are recorded by the CCD. The deviation between these two ellipses is estimated by calculating the deviation of the ellipse centers.

The center of the ellipse is estimated using diameter bisection method [5]. This step enables us a robust detection of the center of the ellipse.

(1) The streak is divided as a short segment.
(2) The angles of all segments are calculated.
(3) A pair of segment that orientations are anti-parallel is found. If such a pair of short segment lies on an ellipse, the midpoint of the line joining the segments will be situated at the center of the ellipse. (Fig.8)
(4) Accumulation of the mid points on the parameter plane for all pairs of corresponding segments.
(5) The center point of the ellipse is determined by finding the peak point on the parameter plane.

Finally, the angle (θ) of the robot against the pipe is estimated by the following equation.

$$\theta = \tan^{-1}(d / L) \tag{4}$$

where, d is a deviation between ellipse centers and L is a distance between parallel lasers (Fig.9).

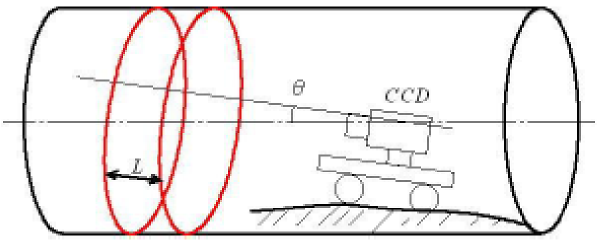


Fig.7 Inclined robot and two parallel lasers

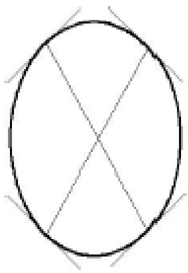


Fig.8 Center detection of the laser streak

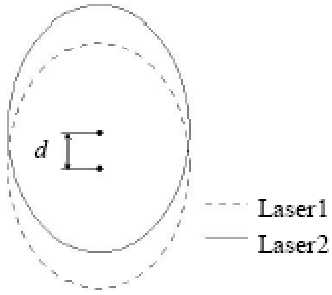


Fig.9 Deviation between two laser streaks

V. Solution of dead angle problem

Fig.10 shows the one example of the reconstructed sewer pipe by measured data. Unmeasured area is existed around the bottom of the pipe by the occlusion. This occlusion is caused by the connecting shaft between CCD camera and a laser projector. In order to eliminate the unmeasured area, shaft rotating unit is equipped on the system as is shown on Fig.11 and Fig. 12. The position of the shaft is changed by the rotation. The measurement is established on two steps by different rotation angle (position) of the shaft. Images on these two steps are combined and unmeasured area can be eliminated as is shown on Fig.13.

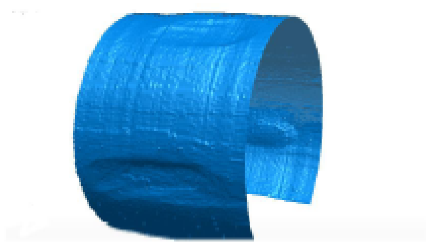


Fig.10 Reconstructed pipe using the old system

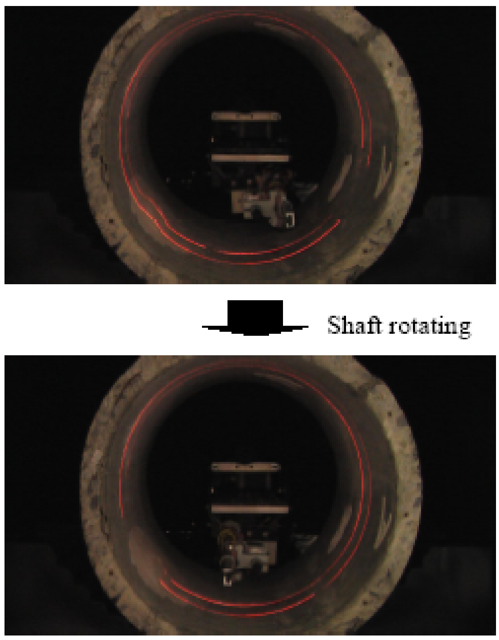


Fig.11 Shaft rotating unit

Fig.12 New robot for measurement

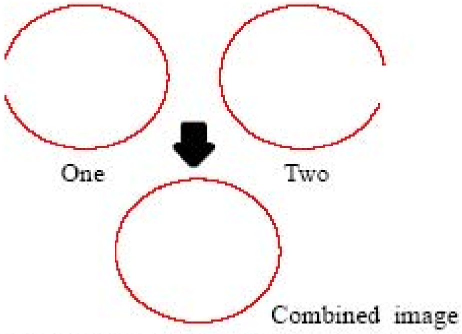


Fig.13 Elimination of unmeasured area

Fig.14 Photograph of the experimental setup

Fig.15 Inside of the measured pipe

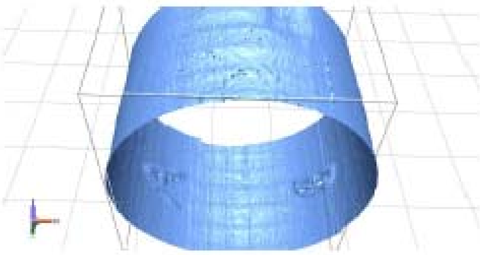


Fig.16 Reconstructed pipe using the measured data

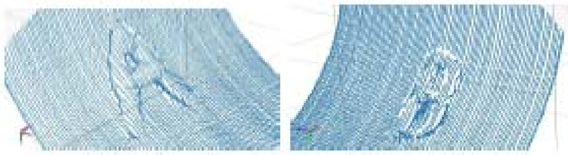


Fig.17 Reconstructed letters

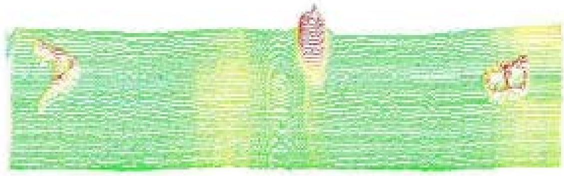


Fig.18 Expanded image of the pipe

VI. Result of the measurement

Experimental setup is shown in Fig.14. Letter 'A' and 'B' made of clay are attached on the pipe as is shown in Fig.15 The cross sections of the pipe are measured and summarized along the axis to reconstruct the shape of the sewer pipe in the computer. The reconstructed pipe and the letters using the measured data are shown in Fig.16 and Fig.17 The computer processes the image of the streak and checks the condition of the pipe. Fig.18 shows the expanded pipe image to detect the uneven surface. The average error of the measurement is under 0.4 mm.

VII. Conclusion

The sewer pipe measurement system is introduced in this paper. Quantitative measurement was realized using parallel lasers and image processing technique. Two parallel lasers enable the detection of the slope of the robot against the axis of the pipe. The each streak could be easily extracted from the image by making the phase difference between two lasers. The average measurement error was about 0.4 mm and it is sufficient for the measurement of the sewer pipe.

References

[1] E.R. Davies, " Machine Visio: Theory , Algorithms, Practicalities", Academic Press. 1990
[2] Carme Torras, "Computer Vision: Theory and Industrial Applications", SpringerVerlag, 1992
[3] Threedimensional Computer Vision, A geometric viewpoint, Oliver Fargeras, 1996
[4] Tsai,R. A versatile camera calibration technique forhighaccuracy 3d machine vision metrology using offtheshelf tv cameras andlenses, IEEE Journal of Robotics and Automation, vol. 3, no. 4(1987),pp. 323–344.
[5] Tsuji, S. and Matumoto, F. "Detections of ellipses by a modified Hough transform", IEEE Trans. Comput. 27, pp. 777781