A New Position Surveying System for the Underground Pipes Using Two Rotary Encoders

Toshiaki HAMANO[1], Manabu ONO[2] and Shigeo KATO[3]

[1] Technos Corp. , [2] Tokyo Metropolitan College of Technology, [3]Nippon Institute of Technology

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Abstract

We fabricated a position surveying system for underground pipes using two rotary encoders. Two rotary encoders measure distance of right and left walls of the pipe. It was confirmed that the fabricated position surveying system can survey the position of the experimental underground pipe that consists of two 8000 mm straight pipes and 4000 mm curved pipe that has the curvature radius of 36500 mm in the error of 5.6 mm.

1. Introduction

Optical fiber cable for the broad bands communication is usually covered by plastic pipe and buried under the ground. Then, we are required to grasp its real buried position before digging at the construction or the maintenance in order to prevent from the cutting of the optical fiber. However, once the optical fiber cable is buried under the ground, it is very difficult to confirm the buried position of the pipe, because the optical fiber cable cable and plastic cover pipe are not the metal.

A former way to confirm the buried position of the optical fiber cable is the ground penetrating radar method [1]-[5]. The ground penetrating radar method is very useful for the metal. However, the optical fiber cable in plastic cover pipe is not metal. Another method is the elastic wave method [6]. In this method, a vibrator is put on the ground. The wave from the vibrator is detected by many in-lined receivers that are arrayed on the ground. However, the detection is only done at the place where the ground is covered by soil and the accuracy of the surveying is not good at the place where the position of the plastic cover pipe is so deep in the ground or in the different soils.

Fortunately the cover pipe of the optical fiber cable goes through utility holes that are arranged in the hundreds meter interval. If we can insert a surveying mechanism into the cover pipe at the utility holes and detect directly the information of the buried position of the pipe by a new position surveying system that can move itself in the

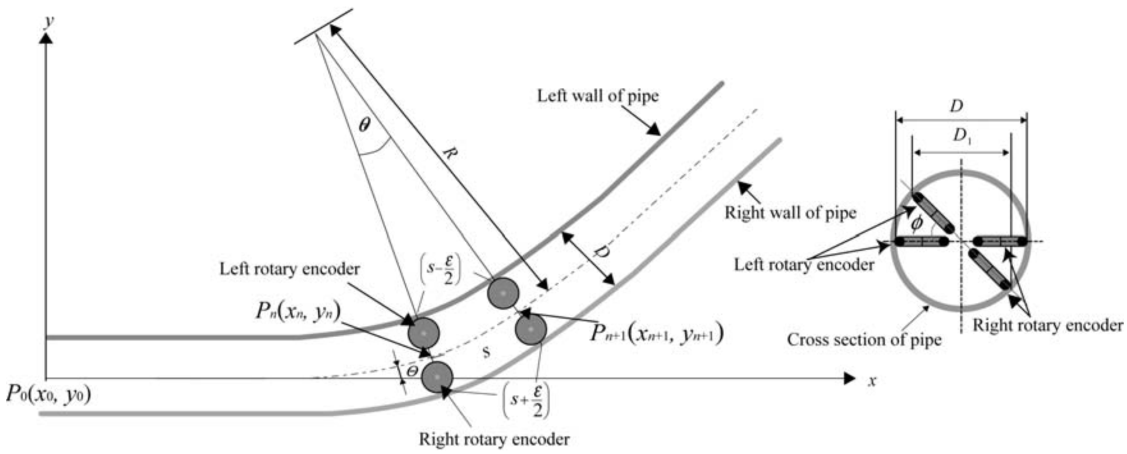

Fig. 1. The principle of the position surveying in the underground pipe by in-pipe surveyor using rotary encoders

pipe, the problem of the former way to confirm the buried position of the optical fiber cable is solved.

This research aims to identify easily the buried position of the pipe, using the information of the buried position from the pipe. We use two rotary encoders that have pulleys contacting right and left walls of the buried pipe in order to detect directly the information of the buried position of the pipe [7]-[9]. Output of the rotary encoder contacting the wall shows the length of the wall. Average of summation of the outputs of the right and the left rotary encoder shows moving distance of a surveying mechanism of the position surveying system. The curvature of the buried pipe is obtained by difference of the outputs of the right and the left rotary encoder. The position of buried pipe is identified by the moving distance and the curvature of the pipe. It is confirmed that the new position surveying system can identify the buried position of a pipe that is 20 m long and has loose curvature in the error of 5.6 mm.

2. Principle of position surveying

Length of walls of both side of a pipe is same if the pipe is straight. If the pipe curves toward right, the length of the right wall is shorter than the length of the left wall. We measure the lengths of both side of the pipe by two rotary encoders that have pulleys. The principle of position surveying using two rotary encoders is shown in Fig. 1. Inner diameter of the pipe that has loose curvature is D. The original point is P_0 (x_0, y_0). Present position of the surveying mechanism is P_n (x_n, y_n). Angle between the tangential line and the x-axis is Θ. It is assumed that a difference ε is made by the both side rotary encoders when the surveying mechanism moves a small distance of s. This moved point is $P_{n+1}(x_{n+1}, y_{n+1})$. The normal lines that cross points P_n (x_n, y_n) and P_{n+1} (x_{n+1}, y_{n+1}) make an angle θ. The radius of the curvature is assumed as R. The surveying mechanism may incline by some rolling force. The rolling angle is assumed as ϕ. Projection of the pulley is D_1 and is shown as

$$D_1 = D\cos\phi \quad (1)$$

The difference ε of the right and left rotary encoders is shown as

$$\varepsilon = \left(s + \frac{\varepsilon}{2}\right) - \left(s - \frac{\varepsilon}{2}\right) = \left(R + \frac{D_1}{2}\right)\theta - \left(R - \frac{D_1}{2}\right)\theta = D_1\theta \quad (2)$$

Then, the small angle θ is obtained as

$$\theta = \frac{\varepsilon}{D_1} \quad (3)$$

The x-coordinates and the y-coordinates of P_{n+1} are calculated from the x-coordinates and the y-coordinates of P_n as

$$x_{n+1} = x_n + s \cdot \cos(\Theta + \theta) \quad (4)$$

$$y_{n+1} = y_n + s \cdot \sin(\Theta + \theta) \quad (5)$$

The tangential angle Θ is the summation of the small angle θ and shown as

$$\Theta = \Sigma\theta \quad (6)$$

3. Pipe for surveying experiment

3.1 Coordinates of the pipe for surveying experiment

Pipe for surveying experiment is shown in Fig. 2. The pipe consists of two straight pipes and a curved pipe. The first straight pipe is 8000 mm long. The second curved pipe has a curvature radius of 36500 mm and is 4000 mm long. The third straight pipe that is attached the second pipe and is 8000 mm long. The x-axis of the pipe for surveying experiment is standardized by a fishing line that is 0.05 mm in diameter and is intensely tightened. Distance from the original point that is the x -coordinates is measured by a tape measure. The y-coordinates is measured by steel measure from the standard line of the fishing line. 199 x-coordinates are obtained, because measure is done from the original point to 19800 mm every 100 mm. The y-coordinates at 19800 mm of the x-axis is 1121 mm. The distance of 100 mm is divided into 30 in the computer, because 100 mm is coarse. Interval is 3.33 mm and number of the position coordinates is 5941. This is called as the experimental position coordinate. Errors by the division occur at the curved pipe. However, maximum of errors is less than 0.034 mm

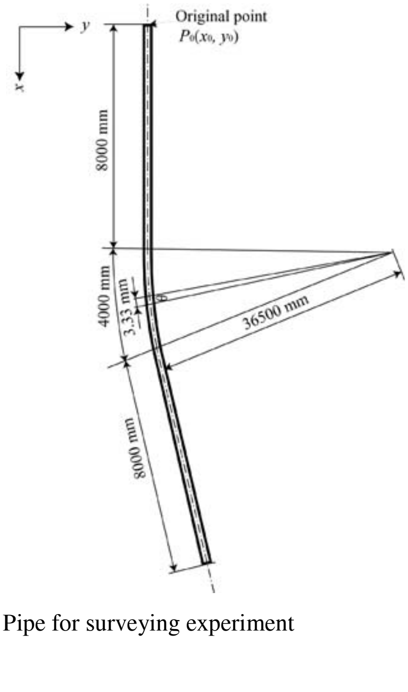

Fig. 2. Pipe for surveying experiment

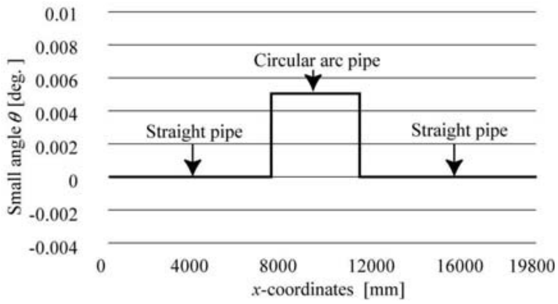

Fig. 3. The small angle θ of the ideal pipe

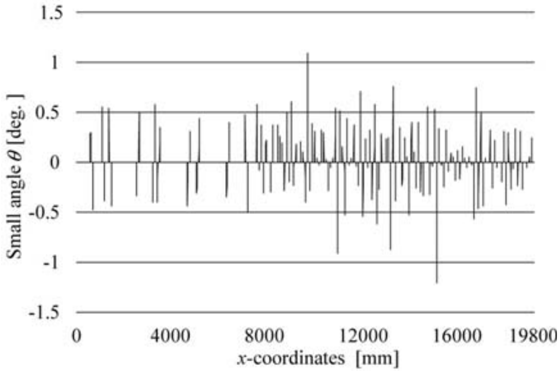

Fig. 4. The small angle θ obtained from position coordinates of the pipe for experiment measured by the steel measure

3.2 Small angle of the pipe for surveying experiment

Here, the ideal pipe for surveying experiment is assumed to consist from two complete straight pipes and a complete circular arc and the small distance *s* is assumed to be 3.33 mm. Then, the small angle is 0 degree at the straight pipes and 0.0053 degrees at the circular arc pipe that exists between 8000 mm and 12000 mm of the *x*-coordinates. The small angle θ of the ideal pipe is shown in Fig. 3. Using Eqs. (4), (5) and (6), the small angle θ and the tangential angle are calculated from position coordinates of 5941 points. Relationship between the small angle θ and *x*-coordinates is shown in Fig. 4. The small angle of 0.0053 degrees that is shown in Fig. 3 is not seen in Fig. 4, because there exist errors larger than 1 degree.

3.3 Averaging process for decreasing of errors

We introduce averaging process in order to decrease large errors. Some small angle θ_n is assumed to be an average of three continuous small angles.

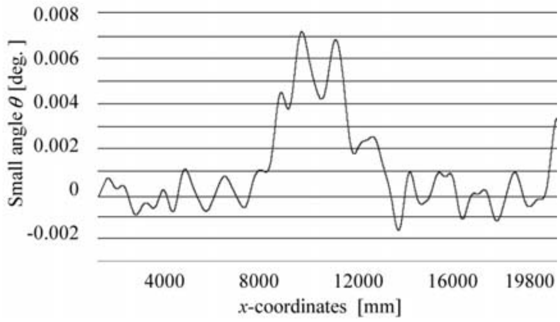

Fig. 5. The small angle θ obtained from position coordinates of the pipe for experiment measured by the steel measure and averaged using the averaging process

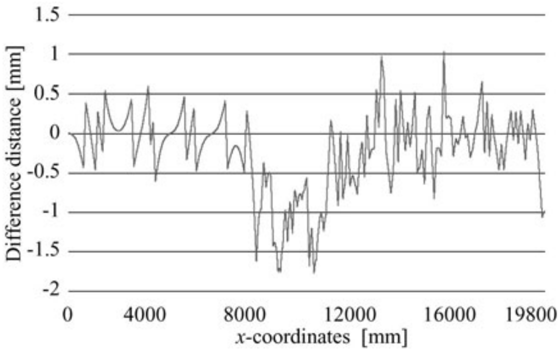

Fig. 6. Difference between the calculated position coordinates and the measured position coordinates

That is,

$$\theta_n = \frac{\theta_{n-1} + \theta_n + \theta_{n+1}}{3} \tag{7}$$

Small angles at both ends do not change. By the averaging process, all small angles except both ends are averaged and changed. The large error is changed to small error. The averaging process of 10000 times is done. The result of the averaging process is shown in Fig. 5. Errors are decreased to the order of 0.001 degrees at the straight pipe. Maximum of small angles at the curved pipe that exist between 8000 mm and 12000 mm of *x*-axis are 0.004 degrees or 0.007 degrees. These small angles are approximate as the small angle 0.0053 degrees of the ideal pipe. Substituting small angles shown in Fig. 5 into Eqs. (4), (5) and (6), 5941 position coordinates are obtained. These are called as calculated position coordinates. Difference between the calculated position coordinates and the measured position coordinates is shown in Fig. 6. Maximum difference is about 1.7 mm at the curved pipe. We use the calculated position coordinates as the standard position coordinates, because the error of the measured position coordinates is considered to be decreased by the averaging process of 10000 times.

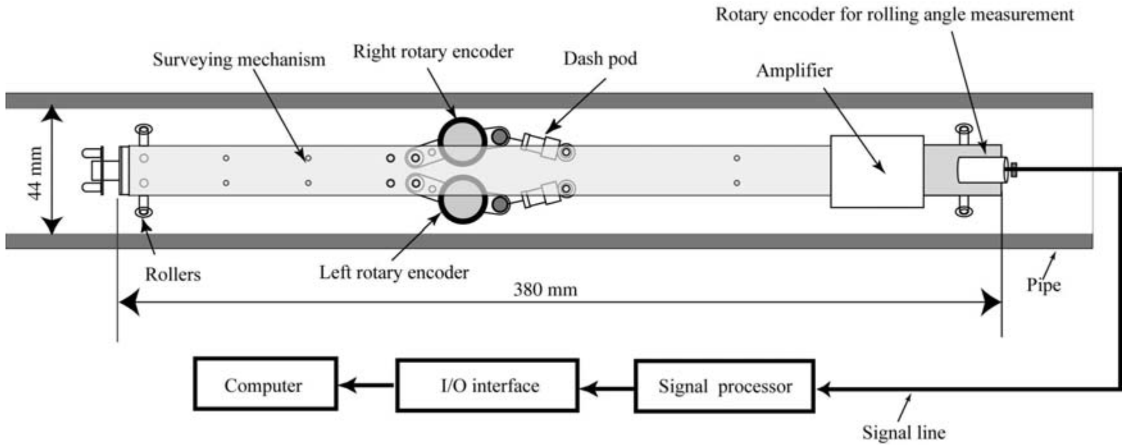

Fig. 7. Structure of the position surveying system

4. Position surveying system

A new position surveying system for underground pipes is shown in Fig. 7. The system consists of a surveying mechanism that carries the right and left rotary encoders, a signal processor, an I/O interface and a computer. The surveying mechanism that is 380 mm long is held to the inside of the pipe by eight small rollers and can move in the pipe. A weight is attached under chassis in order to prevent rolling of the surveying mechanism. However, rolling of the mechanism can not be prevented perfectly. So, rolling angle ϕ is measured by an another rotary encoder that is attached the chassis. The right and left encoders are held by arms that have pin joints and are attached the chassis of the surveying mechanism. The pulley is pushed to the wall of the pipe by force of 1 N and vibration of the rotary encoder is severely damped, because the arm is suspended by a spring and a dash pod. The signal processor consists of a detecting circuit of clockwise or counter clockwise and a mechanical chattering circuit. The rotary encoder makes 1440 pulses per one rotation. Resolution of the rotary encoder is 44 μm. The signal from the signal processor is introduced into the computer through the I/O interface. Software in the computer calculates locus of the surveying mechanism. The result of the position surveying is displayed on the screen of the computer.

5. Surveying results by the position surveying system

5.1 Measured small angle

We measure the position coordinates of the pipe for surveying experiment by the surveying mechanism. A sampling frequency from the rotary encoder is 20 Hz. Number of the sample is about 6800. The small distance s is about 3 mm. Obtained small angles are shown in Fig. 8. The small angle at the ideal straight must be 0 degree.

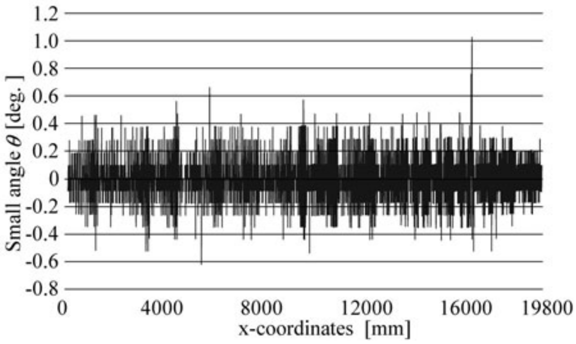

Fig. 8. The small angle measured by rotary encoders of the position surveying system

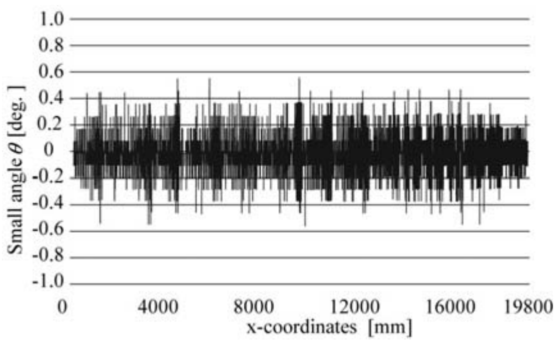

Fig. 9. The small angle eliminated over the optimal threshold

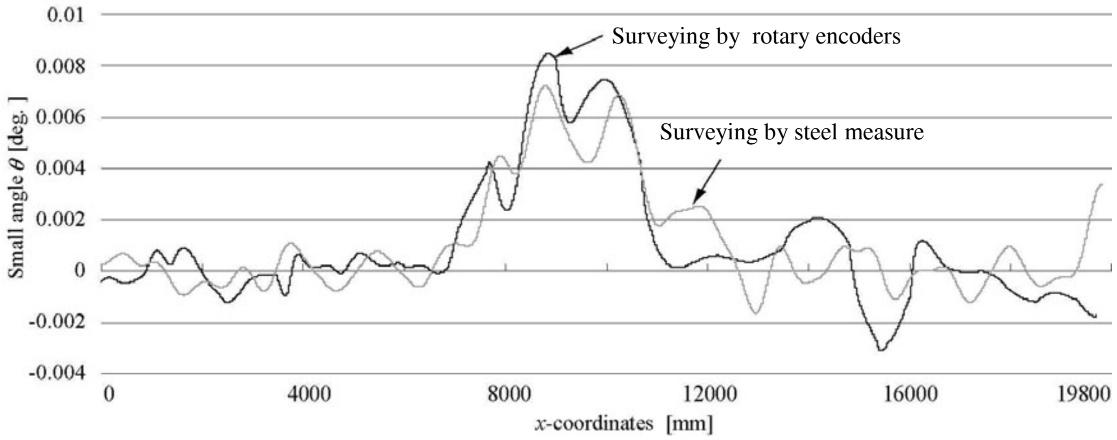

Fig. 10. The small angle after using threshold processing and averaging processing

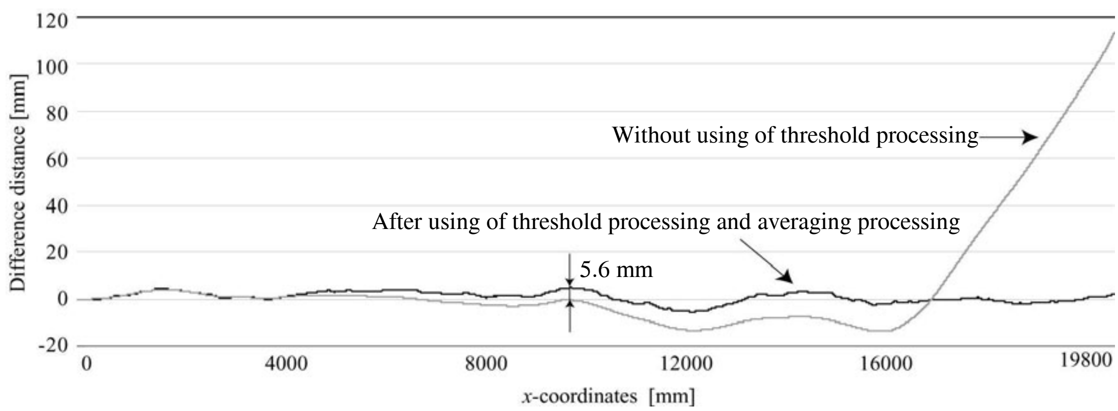

Fig. 11. Difference between the position coordinates measured by rotary encoders and the calculated position coordinates measured by steel measure

However, there exist errors from 0.2 degrees to 0.4 degrees and 1 degree at 16000 mm of *x*-axis. The error is considered to occur at the joint bump of pipes that are 4000 mm long.

5.2 Decreasing of measured error

Large error must be eliminated, because it severely affects afterwards calculation of the position coordinates. A threshold that is a value of the large error is discussed. Optimal threshold is confirmed to be ± 0.55 degrees. The difference between the position coordinate by the rotary encoder and the position coordinate by the steel measure is smallest at the optimal threshold. The small angles that are eliminated over the optimal threshold are shown in Fig. 9. The small angles that are measured by rotary encoders are averaged by using Eq. (7). Number of averaging is 10000. The averaged small angles by the rotary encoder are shown in Fig 10 by dark line. The averaged small angles by the steel measure are also shown in Fig 10 by gray line. They are similar.

5.3 Result of position surveying

The position coordinate by the rotary encoders and the position coordinate by the steel measure are obtained from the small angles shown in Fig. 10. Difference of both position coordinates is shown in Fig. 11. Maximum of the difference occurs at the curved pipe and is 5.6 mm. Difference of both position coordinates without the threshold processing is also shown in Fig. 11. The threshold processing is confirmed to be very effective.

6. Conclusions

1. We fabricated a position surveying system for underground pipes using two rotary encoders. Two rotary encoders measure distance of right and left walls of the pipe.

2. We discussed a threshold of small angles that are obtained by output difference of two rotary encoders. Optimal threshold is ± 0.55 degrees. Large position surveying error occurs without the threshold processing.
3. Some small angle is assumed to be an average of three continuous small angles. Averaging of 10000 times can decrease the measured error.
4. It was confirmed that the fabricated position surveying system can survey the position of the experimental underground pipe that consists of two 8000 mm straight pipes and 4000 mm curved pipe that has the curvature radius of 36500 mm in the error of 5.6 mm.

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