FABRICATION OF A NEW THREE DIMENSIONAL POSITION SURVEYING SYSTEM FOR THE UNDERGROUND LONG DISTANCE PIPES USING FOUR ROTARY ENCODERS

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INTRODUCTION

Optical fiber cable for broadband 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 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\textsuperscript{[1]}. 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\textsuperscript{[2]}. In this method, a vibrator is put on the ground. The wave from the vibrator is detected by many in-lined receivers which 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.

If we can detect directly the information of the buried three dimensional position of the pipe by a new position surveying system that can move itself in the 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 four rotary encoders that have pulleys contacting top, bottom, right and left walls of the buried pipe in order to detect directly the information of the buried position 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 three-dimensional curvature in the error of 39 mm

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 use four rotary encoders that have pulleys contacting top, bottom, right and left walls of the buried pipe in order to detect directly the information of the buried position of the pipe. Output of rotary encoder contacting the wall shows the length of the wall. Average of summation of the outputs of the top, the bottom, the right and the left rotary encoder shows moving distance of a surveying mechanism of the position surveying system. The curvature of vertical direction of the buried pipe is obtained by difference of the outputs of the top and the bottom rotary encoder. The curvature of horizontal direction of the buried pipe is obtained by difference of the outputs of the right and the left rotary encoder. The three dimensional position of buried pipe is identified by the moving distance and the curvature of horizontal direction and the curvature of vertical
direction. The principle of position surveying of horizontal direction using the right and the left rotary encoders is shown in Fig. 1. Inner diameter of the pipe that has loose curvature is \( D \). The original point is \( P_0 \). Present position of the surveying mechanism is \( P_n \). Angle between the tangential line and the \( x \)-axis is \( \theta_z \). It is assumed that a difference \( \varepsilon \) is made by the both side rotary encoders when the surveying mechanism moves a small distance of \( s \). This moved point is \( P_{n+1} \). The normal lines that cross points \( P_n \) and \( P_{n+1} \) make an angle \( \phi \). The radius of the curvature is assumed as \( R \). The difference \( \varepsilon \) of the right and left rotary encoders is shown as

\[
\varepsilon_z = \left( s + \frac{\varepsilon_z}{2} \right) - \left( s - \frac{\varepsilon_z}{2} \right) = \left( R_z + \frac{D}{2} \right) \theta_z - \left( R_z - \frac{D}{2} \right) \theta_z = D \theta_z \quad (1)
\]

Then, the small angle \( \theta_z \) is obtained as

\[
\theta_z = \frac{\varepsilon_z}{D} \quad (2)
\]

Similarly, the curvature of vertical direction is obtained by difference of the outputs of the top and the bottom rotary encoder. The small angle of vertical direction is \( \theta_y \). The surveying mechanism may incline by some rolling force. The rolling angle is assumed as \( \phi \). The \( P_{n+1}(x_{n+1},y_{n+1},z_{n+1}) \) are calculated from the \( P_n(x_n,y_n,z_n) \), \( \theta_z \), \( \theta_y \), \( \phi \), and \( s \).

The coordinates of \( P_{n+1}(x',y',z') \) after \( z \) rotation is

\[
x'_{n+1} = x_n + s \cos (\theta_z + \theta_y) \quad (3)
\]
\[
y'_{n+1} = y_n + s \sin (\theta_z + \theta_y) \quad (4)
\]
\[
z'_{n+1} = 0 \quad (5)
\]

The coordinates of \( P_{n+1}(x'',y'',z'') \) after \( y \) rotation is

\[
x''_{n+1} = x'_{n+1} \cos (\theta_y + \theta_z) \quad (6)
\]
\[
y''_{n+1} = y'_{n+1} \quad (7)
\]
\[
z''_{n+1} = z'_{n+1} \sin (\theta_y + \theta_z) \quad (8)
\]

The coordinates of \( P_{n+1}(x,y,z) \) is what is added the coordinates after \( X \) rotation to the past coordinate of the point \( P_n(x,y,z) \)

\[
x_{n+1} = x_{n+1}' + x_{n+1}'' \quad (9)
\]
\[
y_{n+1} = y_{n+1}' + y_{n+1}'' \quad (10)
\]
\[
z_{n+1} = z_{n+1}' + z_{n+1}'' \quad (11)
\]

The tangential angle \( \theta_t \) is the summation of the small angle \( \theta_z \) and shown as

\[
\theta_t = \sum \theta_z \quad (12)
\]
\[
\phi = \sum \phi \quad (13)
\]
\[
\theta_y = \sum \theta_y \quad (14)
\]

**POSITION SURVEYING SYSTEM**

A new position surveying system for underground pipes is shown in Fig. 2. The system consists of a surveying mechanism that carries the four rotary encoders, a signal processor, an I/O interface and a computer. The surveying mechanism that is 375 mm long is held to the inside of the pipe by eight small rollers and can move in the pipe. However, it is difficult to measure the length of the bottom inside pipe, because the cable exists in the pipe. Consequently, the rotary encoder is inclined 45 degrees and attached to the surveying mechanism. Small angle \( \phi \) is 45 degrees. 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. Therefore, rolling angle \( \phi \) is
measured by another rotary encoder that is attached the chassis. The rotary 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 dashpot. The circumference of a pulley is 64.7 mm. 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 every 64.7 mm. This method decreases an error by the distortion of the pulley. Consequently, Small distance s is 64.7 mm of the same length as the circumference of a pulley. The result of the position surveying is displayed on the screen of the computer.

PIE FOR SURVEYING EXPERIMENT
Pipe for surveying experiment is shown in Fig. 3. The pipe consists of four straight pipes and two circular arc pipes. The diameter of the pipe is 44 mm. The first and second straight pipe is 4 m long. The third circular arc pipe has a horizontal curvature radius of 30 m and is 4 m long. The fourth and sixth straight pipe is 2 m long. The fifth circular arc pipe has a vertical curvature radius of 20 m and is 4 m long. Pipe for experiment measured coordinates on the basis of the laser level. The x-coordinates at 20 m of the y-axis is 1702 mm and z-axis is 284.5 mm.

RESULT OF POSITION SURVEYING
We measure the three dimensional position coordinates of the pipe for surveying experiment by the surveying system. An error is included
in the small angle calculated from the difference in pair rotary encoder pulse. Therefore, the error included in the small angle is eliminated using the average processing and the dynamic threshold processing. The small angle $\theta_z$ eliminated the error is shown in Fig. 4. In the horizontal circular arc pipe of the x-coordinates at 9000 mm, the small angle exists 0.35 degrees. The small angle $\theta_x$ that removed the error is shown in Fig. 5. In the vertical circular arc pipe of the x-coordinates at 15000 mm, the small angle exists 0.22 degrees. The position coordinates of horizontal direction by the position surveying system and the position coordinate of horizontal direction by the steel measure are shown in Fig. 6. The position coordinates of vertical direction by the position surveying system and the position coordinate of vertical direction by the steel measure are shown in Fig. 7. The vertical maximum of difference occurs at the curved pipe and is 39 mm. The horizontal maximum of difference occurs at 14m of x-coordinates and is 30.6 mm. The error of vertical direction by the position surveying system without using the dynamic threshold processing and the average processing is 50 mm. The error of horizontal direction by the position surveying system without using the dynamic threshold processing and the average processing is 250 mm. Consequently, it was confirmed that the dynamic threshold processing and the averaging processing is very effective.

CONCLUSIONS
1. We fabricated of a new three dimensional position surveying system for the underground pipes using four rotary encoders. Four of rotary encoders measure distance of top, bottom, right and left walls of the pipe.

2. The curvature of vertical direction of the buried pipe is obtained by difference of the outputs of the top and the bottom rotary encoder. The curvature of horizontal direction of the buried pipe is obtained by of the outputs of the right and the left rotary encoder.

3. 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 three-dimensional curvature in the error of 39 mm.

REFERENCES