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Methodology of Displacement Detection for Water Supply Pipeline by IMU Sensors

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Abstract

The mechanical behavior of underground buried objects such as water supply pipelines is relatively difficult to be measured and analyzed from the ground. The displacement of the pipe might be caused by ground deformation, leakage or other damage, etc. The displacement is accompanied by a change in the angle of the pipe at the point of connection.

In this study, the bending test was carried out using an IMU(Inertial Measurement Unit) sensor to measure the angular displacement of the water pipe. A MEMS-based triaxial acceleration sensor was used for the IMU sensor. The bending test was carried out to determine the threshold value at the time of breakage of the pipe and vertical pressure was applied to the connection point of the DCIP(Ductile Cast Iron Pipe) and PVC (Poly Vinyl Chloride) pipes. Upon the threshold at breakage, it was found that the pipe was seriously damaged when the angle of the DCIP and the PVC reached to 7.7 and 12.7 degrees, respectively. It was denoted that the DCIP is more sensitive than the PVC when displacement occurs due to direct damage of the water supply pipe or ground deformation. In case of the DCIP, when the strength is superior to that of the PVC pipe but an external force such as the ground deformation of the ground acts, it is judged that the functionality of the water supply pipe can be remarkably reduced even if the displacement is small. Therefore, it is concluded that it is necessary to convert the influence of the change of the threshold value and the ground deformation at the time of failure according to the characteristics of the pipe to DB. From this point, it is noted that the IMU sensor of this study can be used to evaluate the structural diagnosis of the pipe and the risk of the ground collapse due to the ground deformation at low cost.

Keywords: underground pipeline, IMU sensor, displacements, bending test

INTRODUCTION

Most infrastructure facilities buried underground are not properly managed after they are first installed. In recent years, underground structures have been increasingly associated with ground subsidence, and it has reported being an artificial cause such as the inadvertent construction of underground structures, damage to underground pipelines, or aging [1]. As the city developed, the management of the old infrastructure facilities buried underground became more important than anything else. However, since it is difficult to observe with the naked eye, proper maintenance is difficult.

In the case of ground subsidence related to water pipelines, it is mainly caused by leakage. The leakage of the water pipeline is mainly caused by aging or corrosion of pipes. Also, it has been reported that leakage occurs due to the load transferred to the pipe due to the ground load and the ground deformation [2]. Therefore, monitoring the movement of the water supply pipe continually, can reduce the risk of major accidents.

Recently, many measurement technologies have been developed to diagnose the condition of structures by the development of sensors and communication technologies. In the past, contact strain gauges such as strain gauges have been used, and in recent years, techniques based on lasers or images have been developed. However, most of these technologies are expensive and require complex computation. Therefore, it is considered that there are many limitations in maintaining and monitoring underground facilities[3].

Recently, IoT(Internet of Things) technology has been developed and technology development using small, low-priced and easy-to-use products like IMU sensors has been proceeding. However, there are not many cases that have been applied to underground facilities yet. Therefore, in this study, the application method of an IMU sensor to monitor the displacement of water pipes in underground facilities was examined.

IMU SENSORS

IMU sensor application

Inertial sensors usually refer to accelerometers, gyroscopes, magnetometer, etc. The accelerometer outputs the change value of the gravitational acceleration of the object, and the gyroscope outputs the angular velocity of the rotating object. And the magnetometer is a sensor to measure the earth's magnetic field. In addition, these sensors are used in combination with each other in order to correct the error value according to the purpose of measurement. Currently, it can be made the sensor very small based MEMS, it is manufactured in chip shape and it can be applied to various places. It is typically used in the core technology of drones and robots. It is also used as the motion sensor of mobile phones, and the development of indoor navigation is in progress as well [4], [5], [6].

The angle that means the robot's posture is expressed by Roll, Pitch and Yaw. Roll and Pitch are values that indicate how something is tilted relative to the direction of gravity. The sensor used to measure roll and pitch immediately is an accelerometer and a gyroscope.

From the perspective of this pipe in fig. 1, it can be represented like a cylinder and it is judged that it can measure pipe movement. For example, if there is no effect on the horizontal underground load on the pipe, only the vertical value will change the value of the pitch. By using these characteristics, it can measure the pipe motion by changing the roll, pitch, and yaw value after installing the sensor on the pipeline.

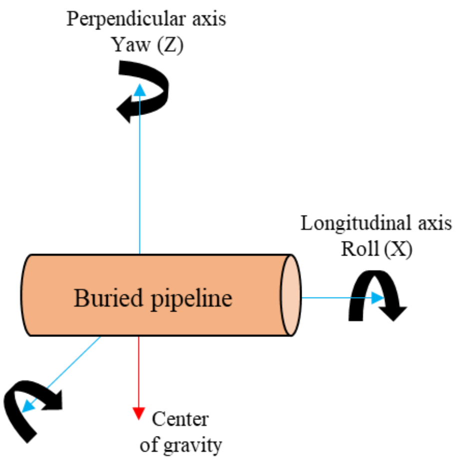
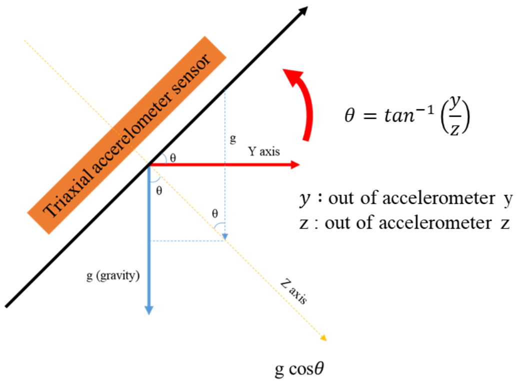


Figure 1. The Roll, Pitch and Yaw of buried pipeline

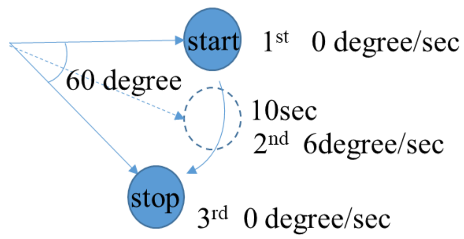
In this study, we used a gyroscope and an accelerometer to measure the displacement of the water pipeline. Looking at the features of accelerometers and gyroscope to measure the displacement of pipes, is as follows:

Accelerometer and Gyroscope

In the case of the accelerometer, since it is basically quietly stopped and gravity acceleration is detected, only the value of -g is output in the z-axis direction as in fig. 2(a). Angle measurement by the accelerometer can be obtained by using a tan function when angle of object changes. However, since the value of the acceleration due to the moving speed is also output, the moving object has the disadvantage that it cannot be distinguished from the value by gravity. It is judged that it can be applied because it does not move in the case of a water supply pipe.



(a) Accelerometer



(b) Gyroscope

Figure 2. Measurement concept of accelerometer and gyroscope

On the other hand, the gyroscope outputs angular velocity. Looking at fig. 2(b), firstly the angular velocity of this object is 0 degree/sec. Next, if the average angular velocity of 10 seconds is tilted about 60 degrees, it is 6 degrees/sec. And then, if it keeps the stop at 60 degrees after tilting, the angular velocity at this time will be 0 degrees/sec again. Overall, it gradually increases from 0 degrees to 60 degrees. Angular velocity means the angle of the time rotation, and if you have to integrate the whole movement time, it can determine the angle the object moved. Therefore, continuously measured results are needed. For the gyroscope, the error increases over time. For these reasons, since the error continues to the measured value due to noise, this error accumulates at the time of integration, so the final value drifts.

Therefore, it is judged that it is not easy to apply a gyroscope to a system in which the displacement is slow in the case of buried objects. Although it can overcome these problems by combining this with an accelerometer, but it is difficult to apply depending on power consumption when using a battery.

Therefore, if applying buried pipeline, it decided that it is reasonable to use the accelerometer, not the gyroscope, to measure the behavior of underground pipes and buried objects. As shown in Fig. 3, when using a 3-axis accelerometer, the pitch can be displayed when the y-axis changes, that is, the pipe displacement due to the vertical load which occurs in the pipe.

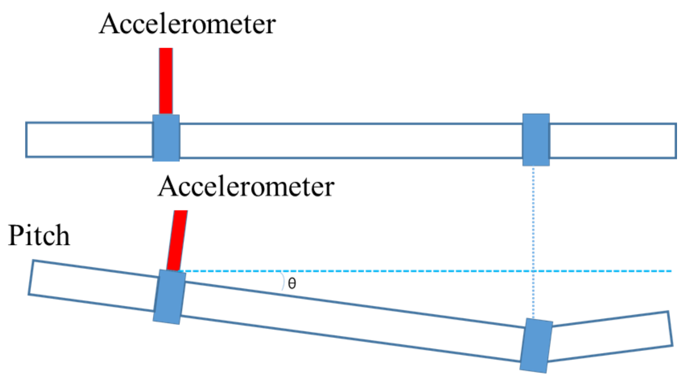


Figure 3. The Accelerometer on water supply pipeline

PIPELINE DISPLACEMENTS DETECTION

Accelerometer error correction

In the case of the accelerometer, since it is basically quietly stopped and gravity acceleration is detected, since the value of the acceleration due to the moving speed is also the output, the moving object has the disadvantage that it cannot be distinguished from the value by gravity.

In the case of a water pipeline, vibration is generated basically. In the case of Fig. 4, it is the result of measuring the vibration when the leak is generated in the water pipeline by the accelerometer. The measurement results in Fig. 4 were measured near the point where the leak occurred, resulting in a vibration of approximately 0.2 g. Since the vibration amplitude of this degree is relatively larger than the vibration generated basically, it can be judged as a leak signal of the water pipeline to judge the abnormality of the pipe. However, vibrations of smaller magnitude can also occur at normal times due to the use of water in the house. Therefore, in order to measure the displacement of the water pipeline, it is necessary to correct the error of such signals. In this study, it was judged that the fundamental vibration occurred less than 0.1g and adjusted to compensate.

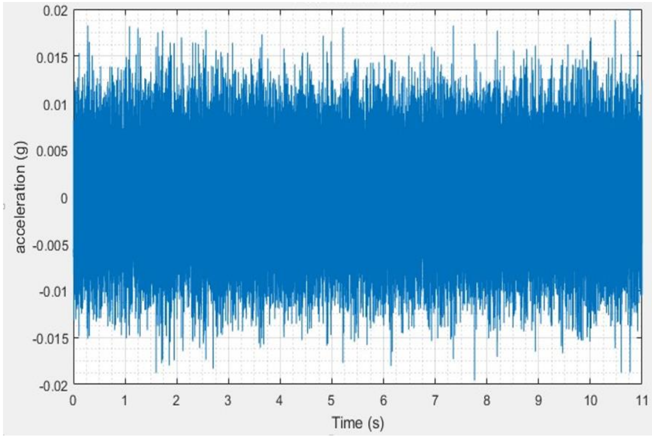


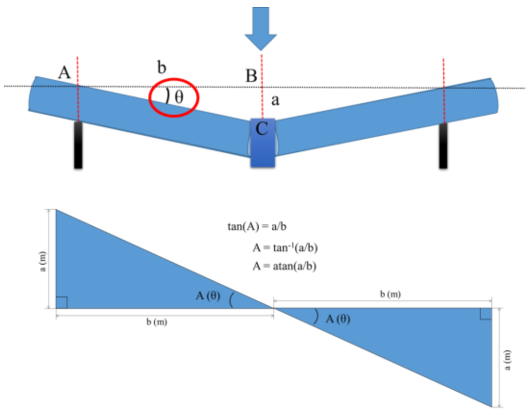
Figure 4. The magnitude of acceleration values in water pipeline during leakage

Pipeline displacements calculation and evaluations

Accelerometers can only measure angles at which the pipeline is tilted, making it difficult to see what happens when the pipe is tilted. It was difficult to grasp what happens when the pipe is tilted several degrees since it can grasp only the angle at which the pipe is tilted. Therefore, it carried out a bending test and used it to record sensor information.

Fig. 5(a) shows the bending test equipment. This device can measure the pressure and the distance moved when the vertical load is continuously applied to the pipeline with a constant load. We conducted a total of three experiments. It was divided into two according to the method of joining the ductile cast iron pipe and the PVC pipe which are currently used most frequently in the water supply pipelines. In the experiment, a pipe was installed in the pipe, and a vertical load was applied to the connection part to measure the threshold value at the time of breakage of the pipe.

(a) Bending test equipment



(b) Pipeline displacements calculation

Figure 5. Measurement equipment and calculation of pipeline displacements

However, since only the distance traveled at the time of breakage is different from the angle information measured by the sensor, there was a limit to using the experiment results directly.

Therefore, it was converted to an angle value by utilizing the length of the pipe and the distance moved by the load. The conversion method is the same as calculating the measurement results of the accelerometer by arc tangent function as fig. 5(b).

Table 1. Summary of bending test results

	DCIP	PVC	
	KP Mechanical joint	Bell joint	Clip Mechanical joint
Pipe length (mm)	670	400	400
Max. Loading (kN)	29.4	8.6	5.9
Angle (Degree)	7.7	12.7	13.2

Table 1 shows a summary of the threshold at the time of pipe breakage by bending test.

The ductile cast iron pipe's results appear more than three times larger than the PVC pipe when loading the pipe. These characteristics are that the metal pipe is more secure against the external load due to the difference in strength between the metal pipe and the nonmetallic pipe.

On the other hand, we noticed that the moving angle at break was about 8 degrees for DCIP and about 13 degrees for PVC. Ductility characteristics of metal pipes and nonmetal pipes are judged to be different, and it is judged that nonmetallic pipes with high ductility are rather stable in the case of the large area of ground deformation.

CONCLUSIONS

In this study, the application method of using an IMU sensor to monitor the displacement of water pipes in underground facilities were examined. The conclusions are as follows.

1. It is relatively efficient to observe the change in angle using the accelerometer to measure the displacement of a water pipeline. However, it is necessary to correct the fundamental vibration of the pipe.
2. In the bending test, the ductile cast iron pipe was 8 degrees, the PVC pipe was about 13 degrees and the critical angle road appears when it was broken. If such dataset is made into a database, the state of the pipe can compare with the information measured using the accelerometer and it is judged that it can be utilized to diagnose buried pipelines.

In this research, only three axis acceleration sensors were used, but it is judged that a very small chip type IMU sensor can be utilized diversely to diagnose underground objects.

ACKNOWLEDGMENTS

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