World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:5, No:10, 2011

Development of 3D Coordinates and Damaged Point Detection System for Ducts using IMU

Ki-Tae Park, Young-Joon Yu, Chin-Hyung Lee and Woosang Lee

Open Science Index, Civil and Environmental Engineering Vol:5, No:10, 2011 publications.waset.org/7787.pdf

Abstract**—**Recently, as the scale of construction projects has increases, more ground excavation for foundations is carried out than ever before. Consequently, damage to underground ducts (gas, water/sewage or oil pipelines, communication cables or power cable ducts) or superannuated pipelines frequently cause serious accidents resulting in damage to life and property. (In Korea, the total length of city water pipelines was approximately 2,000 km as of the end of 2009.) In addition, large amounts of damage caused by fractures, water and gas leakage caused by superannuation or damage to underground ducts in construction has been reported. Therefore, a system is required to precisely detect defects and deterioration in underground pipelines and the locations of such defects, for timely and accurate maintenance or replacement of the ducts. In this study, a system was developed which can locate underground structures (gas and water pipelines, power cable ducts, etc.) in 3D-coordinates and monitor the degree and position of defects using an Inertial Measurement Unit (IMU) sensing technique. The system can prevent damage to underground ducts and superannuated pipelines during construction, and provide reliable data for maintenance. The utility of the IMU sensing technique used in aircraft and ships in civil applications was verified.

Keywords**—**IMU, Pipelines, 3D-Coordinate, monitor.

I. GENERAL INSTRUCTIONS

LARGE scale accidents causing bodily injury and/or property damage in multi-purpose structure maintenance/repair work have occurred with great frequency in recent years. Gas explosions in underground pipelines (gas city/sewer water, communication cables, oil, etc.) or fractures of superannuated pipelines are some examples. The occurrence of such accidents requires precision information concerning the location of old pipelines. (The total length of city water and sewer pipelines in Korea was about 2,000 km as of the end of 2009.) The economic losses incurred by fractured pipelines are serious, and water and gas leakage due to accidents during construction or repair are major concerns. To this end, a system is necessary which can detect defects and deterioration in pipelines, and their location to identify those in need of repair or replacement. This study proposes new maintenance system providing precise pipeline defect detection and location information.

II. UNDERGROUND PIPELINE MAINTENANCE SYSTEM DEVELOPMENT

A. System Concept

The system developed in this study comprises a control/intellectual sensor system (3D coordinates setting function) integrated with an IMU sensor and an tiltmeter; a distance measuring wheel which can read travel distance; and an optical sensor which can detect damaged points. Applicable pipelines include gas lines, city and sewer lines, communication cable conduits, power cable conduits, oil pipelines and other important underground conduits. The system can be controlled by remote monitoring and provide 3D coordinates and simultaneous damage location from the results. Fig. 1 and Fig. 2 below show the principle of IMU sensing and schematic diagram of the system, respectively.

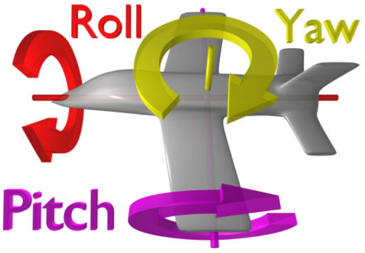


Fig. 1 Principle of IMU sensing

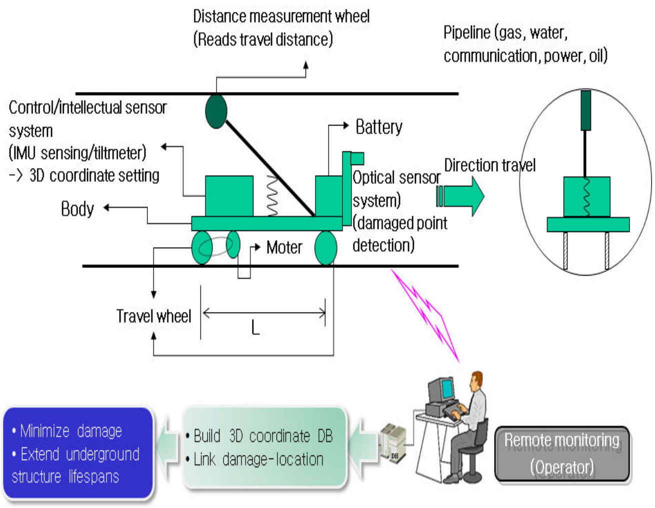


Fig. 2 Schematic Diagram of the System

Ki-Tae Park is with the Korea Institute of Construction Technology, South Korea,(phone: 82-31-910-0134; fax: 82-31-910-0121; e-mail: ktpark@kict.re.kr).

Young-Joon Yu is with the Korea Institute of Construction Technology, South Korea,(yjyou@kict.re.kr)

Chin-Hyung Lee is with the Korea Institute of Construction Technology, South Korea,(ifinder@kict.re.kr)

Woosang Lee Lee is with the Smart C&S, South Korea,(s_lws@daumn.net)

Open Science Index, Civil and Environmental Engineering Vol:5, No:10, 2011 publications.waset.org/7787.pdf

Fig. 3 & 4. shows a data logger diagram and a transport plan containing IMU sensor, respectively.

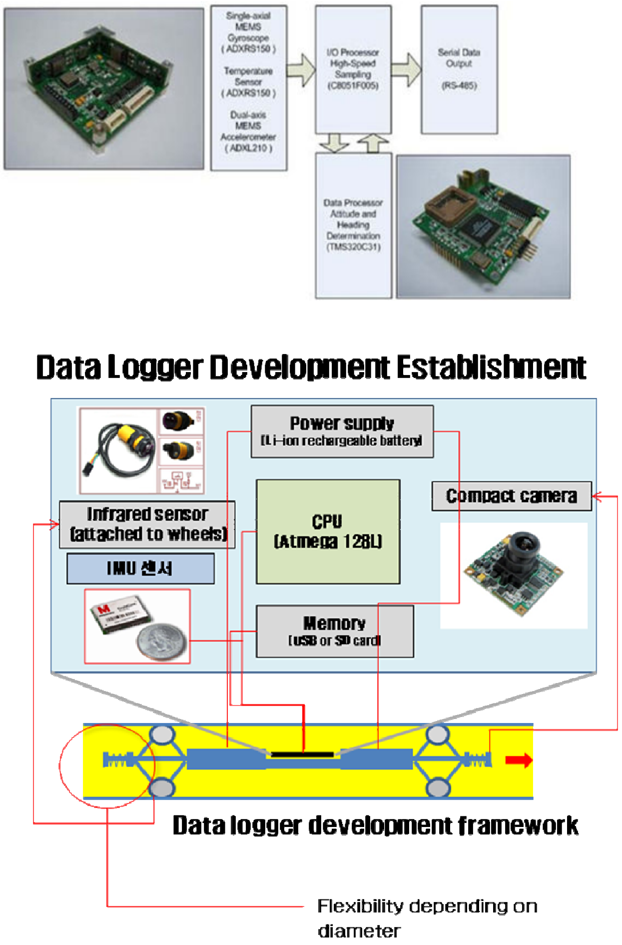


Fig. 3 Data Logger Diagram Containing IMU Sensor

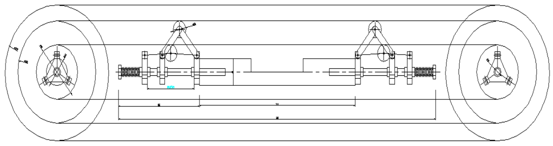


Fig. 4 Transport Plan

The IMU (Inertial Measurement Unit) measures the linear acceleration and rotational angular velocity of the body, using an inertial and acceleration sensor gyroscope (Barbour, N and Schmidt, G (2001)). As the position or location of the apparatus is obtained by integrating linear and rotational accelerations output from the IMU, errors continuously influence on the results [2]. A process of investigating and compensating for inertial sensor error characteristics and estimating error parameters is thus necessary [3].

Roll, Yaw, and Pitch values obtained from the inertial navigation system must be converted into the ground coordinate system values.Fig.5 shows the relationship of the ground coordinate system and Roll, Yaw, and Pitch. The Z-axis becomes the direction of the center of the earth at the vehicle departure point. At the time the X and Z-axis makes 90°, the direction of the vehicle also makes 90°. The Y-axis is 90° with the plane that makes the Z and X-axis, and it's set to the direction of the vehicle. When the height of the pipe is constant and maintains a perfect straight line, the vehicle coordinate progress will move along the Y-axis of the ground coordinate system. But because the pipe maintaining a perfect straight line is impossible, the Roll, Yaw, and Pitch values are measured based on the progress of the vehicle. As a result, the Y-axis and the progress direction of the vehicle don't agree.

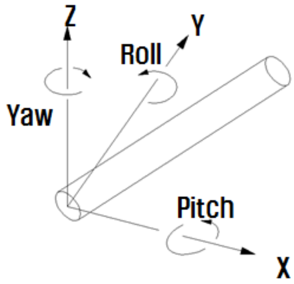


Fig. 5 Roll, Pitch, Yaw

1) *Moving Distance Calculation*

In the case of general inertial navigation systems, the travel distance are calculated by use of the accelerometer. By double integrating the acceleration is a way of obtaining the travel distance. But in the case of pipelines, a much stabilized travel speed is guaranteed and because the assigned vascular bundle is moved, one can use the RPM of a transport's wheel (Fig. 6) instead of an accelerometer to get the travel distance.

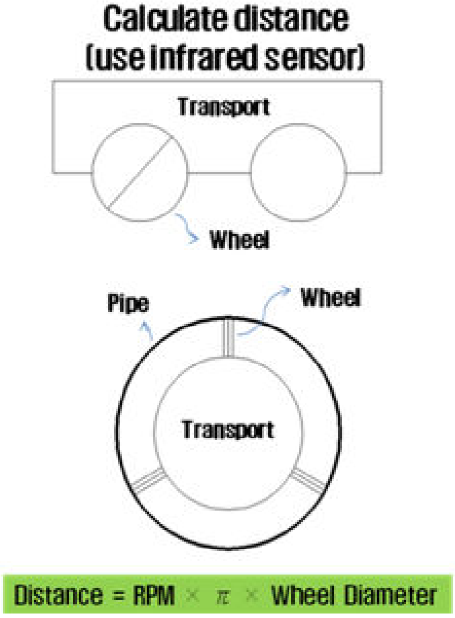


Fig. 6 Transport Concept

2) *Z Coordinate Calculation*

The Z coordinates based on the ground coordinate system get influence from the values of the Roll and Pitch values (out of

Open Science Index, Civil and Environmental Engineering Vol:5, No:10, 2011 publications.waset.org/7787.pdf

Roll, Yaw, and Pitch). However, because the center of the vehicle is the coordinate that needs to be found, the Roll value cannot influence; only the influence from the Pitch value is considered. The Z coordinate can be calculated by multiplying the distance the vehicle traveled and sin(Pitch).

Z coordinate = travel distance × sin(Pitch)

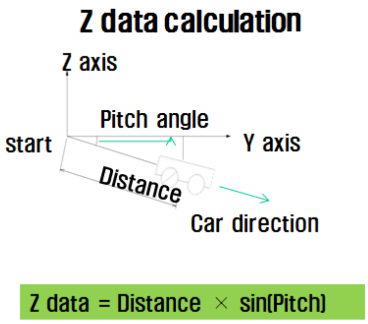


Fig. 7 Z-axis Coordinate Calculation

3) *X, Y Axis Calculation*

The X, Y coordinates based on the ground coordinate system are influenced by the Pitch and Yaw values (out of Roll, Yaw, and Pitch). In the calculation of the Pitch value in Fig. 8, the travel distance (which is the intersection) is directly used to produce the Z coordinates. In the calculation of X, Y coordinates, they are converted to the horizontal distance.

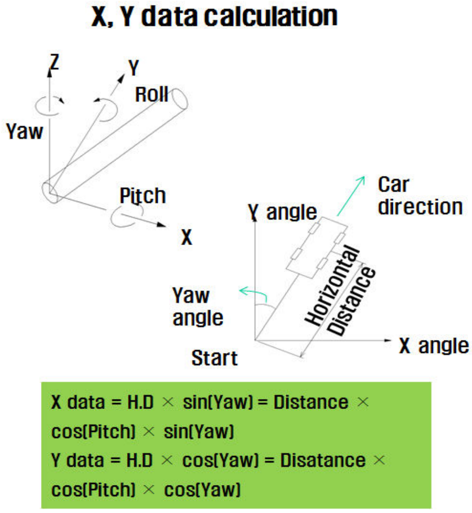


Fig. 8 X, Y Axis Coordinate Calculation

Horizontal distance = travel distance × cos(Pitch)

The X, Y, Z coordinates written above can be organized in a matrix.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = l \begin{pmatrix} \cos P & 0 & 0 \\ 0 & \cos P & 0 \\ 0 & 0 & Sin P \end{pmatrix} \begin{pmatrix} \sin Y \\ \cos Y \\ 1 \end{pmatrix}$$

Here, l: travel distance, P: Pitch angle, Y: Yaw angle

B. *Implemented Apparatus*

A picture of the apparatus developed in this study and the schematic diagram of the pipeline 3D position detection system using the data acquired with IMU are shown below. The total length of the device is 50cm, featuring a logger board comprising an IMU sensor, a CPU and memory. Movement is carried out via wheels arranged in a triangular configuration at both ends. The travel device is designed to be adjusted to fit the diameter of the pipeline. The contact sensor on the wheel counts the rotation to calculate travel distance.

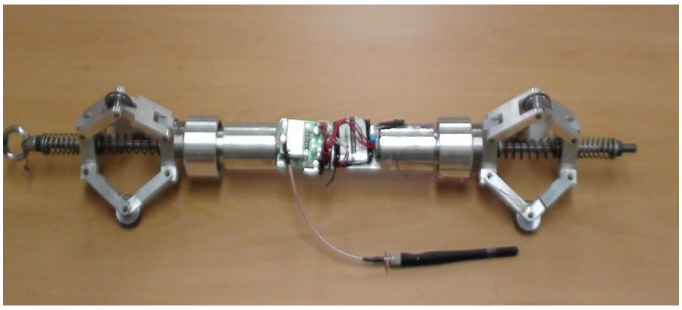


Fig 9 3D Pipeline Position Detection Apparatus which uses Data Acquired via IMU

C. *Performance Verification Test*

1) *Test Procedure*

To verify the utility of the proposed system, a test line was fabricated in the form of sewer pipe. For testing, an underground pipeline was installed, with support fabricated to apply shaking a slope set up to add irregularities. The test line consisted of 13 x 4 m pipes with 12 joint sockets, and a total length of 52 m. The slope was set up with a line. For primary testing, the pipeline was tested using the underground pipeline inspection system to calculate an average value. Fig. 10 below shows the pipeline installed for the test.

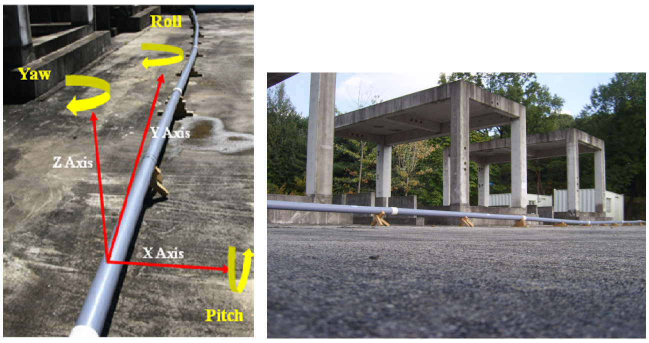


Fig. 10 Pipeline for Test

Fig. 11 below shows pipeline measurement to obtain precise 3D coordinates with the total station, and measurement results.

Open Science Index, Civil and Environmental Engineering Vol:5, No:10, 2011 publications.waset.org/7787.pdf

Fig. 11 Coordinate Measurements

The figures below show the results of the 1st test and views of the testing.

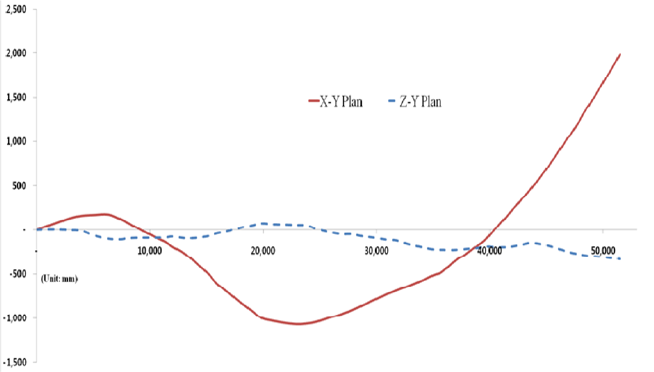


Fig. 12 Test Pipeline Measurement Results

Fig. 13 View of Testing

In the test, the travel device was connected with two lines at both ends, then inserted into the pipeline. The device was pulled from the opposite end of the pipeline via the line. Data was acquired using a wireless module which transmitted it from the data logger to a PC on real-time basis.

2) *Test Result*

Fig. 14 below presents slope measurement results obtained from the test in 3 axes by distance . With the measurement results, 3D pipeline coordinates were estimated and presented in Fig. 8 compared with the results of actual measurement.

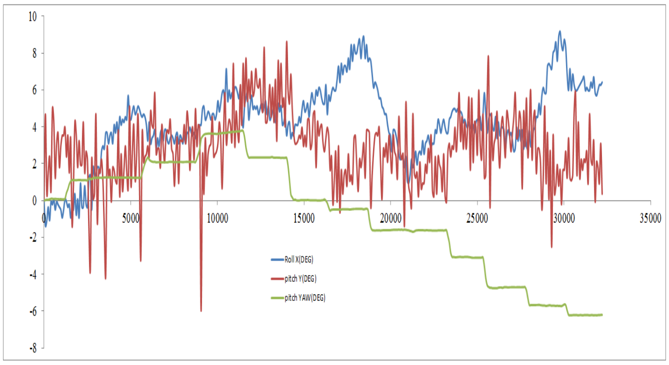
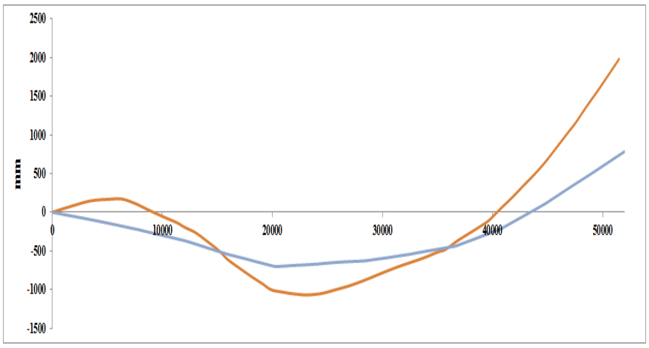


Fig. 14 Slope Measurement Result

Open Science Index, Civil and Environmental Engineering Vol:5, No:10, 2011 publications.waset.org/7787.pdf

According to the test results, the errors at the pipeline end in the X-Y and Y-Z planes were approximately 1,000mm and 400mm, respectively. However, the overall pipeline configuration was in agreement, where error increased according to distance. It is determined that these errors can be compensated for through error correction by distance.

- *X-Y Plane*



- *Y-Z Plane*

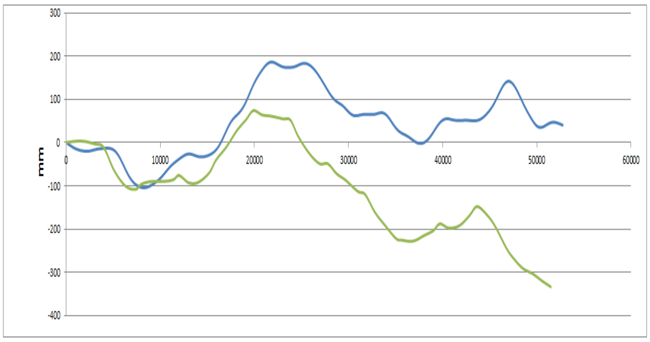


Fig. 15 Test Results

D. 3D Pipeline Coordinates & Image Data Connection Program Development

In this study, for the 3D coordinates of the pipe and pictures inside the pipe estimated by the equipment connecting program development, a small camera (Fig. 16) is used. As for the functions of this program, after the damaged state of the inside of the pipe is saved as an image file, the damaged location is connected with the estimated pipeline 3D coordinates to obtain accurate damaged location information. Data storage uses connection sensors attached to the wheel of the transport; as the wheel rotates, the image of the inside of a pipe is created and saved. This is the way it is planned to function. Obtaining accurate damaged location and image through the connection task of stored image data and estimated 3D coordinate value is possible for the manager. Fig. 17 shows the concept of the program that is to be developed in this study.

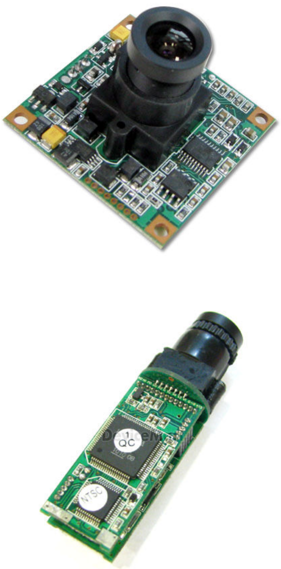


Fig. 16 A Small Camera that can be attached to Transports

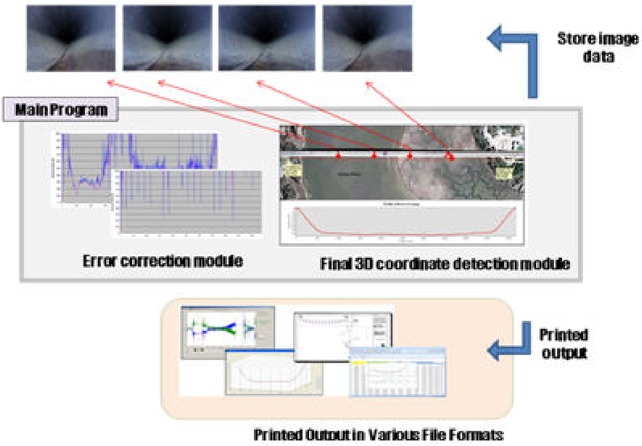


Fig. 17 Development Program Concept

III. CONCLUSION

This study proposes precise 3D position detection and damage detection techniques to secure the safety of underground pipelines. An apparatus implementing such techniques was designed and fabricated, and verified through testing. The test results showed that the proposed system, based on the IMU technique, can be effectively applied in the field by applying the appropriate error correction by distance. The proposed system will be applicable for disaster sites, site information acquisition, construction sites, urban planning, and GIS. The system is expected to be able to help prevent large scale accidents by acquiring and managing cost effective wide area disaster prevention monitoring information in real-time. In addition, the system may be used in structure safety diagnoses , and will be particularly effective in the maintenance of inaccessible facilities.

ACKNOWLEDGMENT

This paper is supported by basic project of KICT(Project title is Development of 3D Position of Pipe Structure & Damage Position Detection System by using IMU Sensing Methodology).

REFERENCES

[1] Barbour, N and Schmidt, G., “Inertial Sensor Technology Trends”, IEEE Sensor Journal, Vol. 1, No. 4, pp.332~339, 2001.

[2] Krohn, A., Beigl, M., Decker, C., Kochendofer, U., Robinson P. and Zimmer T., Inexpensive and Automatic Calibration for Acceleration Sensors, In Proceedings of 2nd International Symposium on Ubiquitous Computing System, 2004.

[3] Cho, S.Y., Park, C. G. and Lee, D. H., “Calibration of a Redundant IMU with Low-Grade Inertial Sensors” The Korean Society for Aeronautical & Space Sciences, Vol. 32, No. 10, pp.53~59, 2004

Open Science Index, Civil and Environmental Engineering Vol:5, No:10, 2011 publications.waset.org/7787.pdf