Underground Monitoring Systems using 3D GIS for Public Safety

Kwangsoo Kim, Dong-Hwan Park, Jaeheum Lee, and Inwhan Lee
UGS Convergence Research Division
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea 34129
Email: {enoch, dhpark, ljh, ihlee}@etri.re.kr

***Abstract*—This paper describes an underground monitoring system using 3D geographic information system (GIS), which models and shows real world objects. This system consists of wireless sensor networks, middleware, and a 3D visualizer. The wireless sensor networks provide sensing values on the state of underground facilities, the middleware provides an abstraction layer for various sensing devices and communication protocols, and the 3D visualizer shows the shapes, the locations, the states, and the risk indexes associated with facilities. The 3D GIS used in the visualizer provides a powerful tool that enhances the ability to monitor the underground environment for public safety and helps improve the efficiency of the underground safety management.**

***Keywords*–Underground facility; underground safety; 3D GIS.**

I. INTRODUCTION

In the industrial society, human beings moved from rural to urban areas during the industrial revolution. Therefore, the number of people living in cities increased dramatically. According to the Economist, about 86 percent of the developed world and 64 percent of the developing world will be urbanized by 2050 [1]. More than 50 percent of the world′s human population now live in cities. This portion will increase continually. As the population of large cities has increased, people have developed an infrastructure to support their comfortable life. The infrastructure was very important for the urban dwellers. In the cities, water pipes were constructed underground to transport water from water sources to individual homes, factories and buildings. Sewer systems were also constructed underground to transport sewage from places to the outside of the cities. Roads were constructed to better facilitate the movement of important things such as food, soldiers, vehicles, and other goods. In modern cities, underground railway systems have been constructed to solve the heavy traffic congestion.

Presently, the outdated and aging infrastructure is becoming a problem. As many cities depend on extensive infrastructure systems that support them, the aging infrastructures are in need of repair or replacement to provide urban dwellers with a comfortable life. For example, New York City′s water mains were installed underground more than 100 years ago. Breaks occur frequently. Since 1998, more than 400 main water breaks have happened every year in New York City [2]. Also, road subsidence in downtown areas in Korean cities has emerged as a serious social problem. For example, the road subsidence in Seoul City occurred at 3,328 locations from 2010 to 2014 [3]. In addition, subsidence occurred in Busan, Incheon, Gwangju, Suwon, Suncheon, Andong, and elsewhere. Unfortunately, it is very hard to recognize the place and time of the leaks or breaks of water pipes and road subsidence. Furthermore, failures of underground facilities are invisible. Sometimes we do not know where they are under the roads.

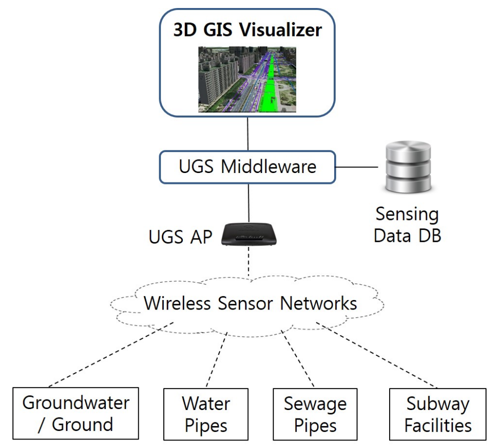

Figure 1. Architecture of Underground Monitoring System.

We have developed an underground monitoring system to detect the state changes occurring in the underground space. To achieve this goal, the underground monitoring system monitors the state changes of sewer pipes, water pipes, subway lines, subway stations, and groundwater levels. Figure 1 shows the architecture of the underground monitoring system. We install various types of sensing devices underground and acquire the sensing data related to the state of the utilities. In Figure 1, the underground safety middleware (UGS-M) is responsible for collecting data from those sensing devices. The locations of all utilities and sensing devices are shown in the 3D visualization module using GIS technologies. Thus, the purpose of this paper is to introduce the underground monitoring system for public safety.

The remainder of this paper is organized as follows. Section II describes wireless sensor networks that transmit sensing data. Section III describes the UGS middleware that collects and manages sensing data. Section IV describes the visualizer that displays geographic data and sensing data. Finally, Section V concludes this paper.

II. WIRELESS SENSOR NETWORKS

We use a wireless sensor network (WSN) to sense the states of underground utilities and transmit them to a centralized data collector. A WSN consists of two types of devices: an access point (AP) and a sensor node. They form a star topology. An AP interconnects a WSN and an IP-based network. An AP provides diverse communication schemes such as wireless fidelity (WiFi), Ethernet, and long term evolution (LTE). A sensor node includes one or more transducers. One transducer

 ISBN: 978-1-61208-469-5

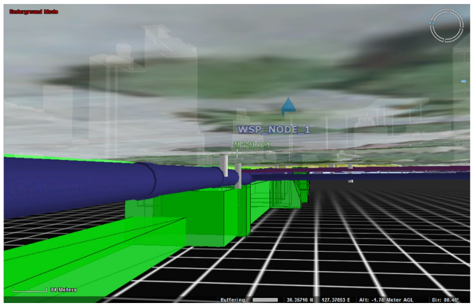

Figure 2. Underground facilities.

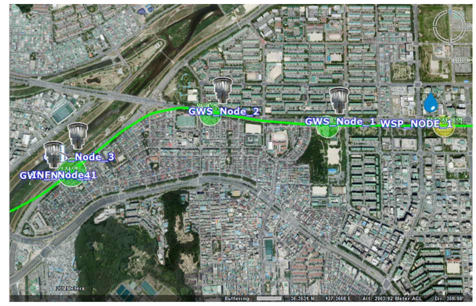

Figure 3. Node overlay and risk index.

Figure 4. Visualization of underground space.

is either a sensor or an actuator. Sensor nodes are installed in tube wells and subway stations and attached to sewer pipes, water supply pipes, and subway lines.

Underground utilities generate different sensing types according to their properties. Sewer pipes generate videos and still images that show their states. Water pipes generate pitch (lateral axis), roll (longitudinal), and leak noise. Subway lines and stations generate videos, still images, the amount of influent water, stress, and acceleration. Tube wells generate water level, water temperature, water conductivity, water turbidity, soil temperature, soil conductivity, and soil moisture. Most of the sensing values are transmitted to the UGS-M through the WSN; however, videos and still images are uploaded into the database through the Internet.

III. UGS MIDDLEWARE

UGS-M is located between several applications including the 3D GIS Visualizer and the sensor networks consisting of a larger number of sensor nodes. UGS-M is responsible for collecting data from the sensor networks, transmitting it to the applications, and providing an abstraction on diverse specifications of sensing devices and communication protocols. To achieve this goal, UGS-M consists of a communication manager, data translator, resource manager, sensing data manager, monitoring manager, and a service interface [3].

IV. 3D GIS VISUALIZER

The 3D GIS visualizer creates a detailed model that describes the objects both from above and below the city ground. The model includes maps, imagery, and subsurface features such as water pipes, water supply manholes, sewage pipes, sewage manholes, subway lines, and subway stations. The GIS data, which represents the underground features, is provided by Daejeon Metropolitan City. Daejeon generates the underground features as the two-dimensional objects. Water pipes, sewage pipes, and subway lines are represented as the line object. Manholes are represented as the point object. Subway stations are represented as the polygon object. Daejeon City uses the GIS data to recognize which underground facilities are located within construction areas. Therefore, we convert two dimensional objects into three dimensional objects by adding its depth and pipe size to display the state information such as cracks on the facilities, slopes of sewage pipes, etc. The underground facilities represented as three dimensional objects are shown in Figure 2. Figure 3 shows the sensor nodes overlaid on the map. Since the road subsidence has occurred mainly along the subway lines, the sensor nodes were installed near the subway lines (marked in green) initially. Figure 3 also shows the risk indexes represented as circles in different colors. Green, yellow, and red indicate low, medium, and high risk, respectively. The sinkhole risk index (SRI) in Figure 4 shows the degree of risk associated with each underground facility. Its value is between 0 and MAX. Figure 4 shows the underground space with the dangerous sewage pipes that are marked in red.

V. CONCLUSION

This paper presents the brief features of an underground monitoring system to detect the risks related to underground utilities. We implemented and evaluated the prototype of this system. It senses the states of utilities, collects the sensing values, and visualizes those values and objects. We are going to implement several analysis schemes that extract both state changes and risks from the sensing values associated with underground utilities. Then, we will apply this system to a testbed to be implemented in Daejeon. In the testbed, the correctness and efficiency of those schemes will be evaluated.

ACKNOWLEDGMENT

This work was supported by the National Research Council of Science & Technology (NST) grant by the Korea government (MSIP) (No. CRC-14-02-ETRI).

REFERENCES

[1] Economist, “Urban life: Open-air computers,” Special reports: Technology and geography, 2012.

[2] A. Forman, “Caution Ahead,” Report published by the Center for an Urban Future, Mar. 2014.

[3] K. Kim, D. H. Park, J. Lee, and S. I. Jin, “UGS Middleware for Monitoring State of Underground Utilities,” in Proceedings of the International Conference on Information and Communications Technology Convergence (ICTC) Oct. 28–30, 2015, Jeju, Rep. of Korea. The Korean Institute of Communcations and Information Sciences, Oct. 2015, pp. 1186–1188.