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Three-dimensional Underground Facility Automatic Renewal System Construction to Updated Integrated Underground Spatial Map

Ji Song Ryu, Dong Hyun Park, and Yong Gu Jang*

Korea Institute of Civil Engineering and Building Technology,
283, Goyangdae-Ro Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do 10223, Korea

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Integrated underground spatial maps have been under construction in South Korea since the 2015 demonstration project as part of ground subsidence preventive measures aimed at augmenting underground safety management. However, the Integrated Underground spatial map constructed for each region at the time remained unchanged until now because of the absence of a renewal system. A clear statement on the obligatory submission of construction completion reports for underground information subject to changes and updates is found in Article 42, paragraph 2 of the Special Act on Underground Safety Management. However, the collection of reports is impeded by difficult access to the submission system and a lack of submission standards. Therefore, the Ministry of Land, Infrastructure, and Transport required by law the direct submission of reports through an online submission system for construction completion reports who underground space developers. In this study, a standard database for construction completion report submission was designed to create an automatic renewal system based on the submitted reports. By presenting the framework for three-dimensional underground facility model processing and renewal automation, a method of rapidly building a three-dimensional underground facility model at minimum cost is presented.

1. Introduction

1.1 Background and purpose

In 2014, South Korea issued "ground subsidence prevention measures" in response to continuous underground safety accidents, such as ground subsidence and depression.(1) These measures included a plan to establish a "three-dimensional (3D) map that can visualize the underground space at a glance". This plan began to unfold in October 2015 as a pilot project entitled the "Integrated Map of Underground Spaces" in accordance with the "formulation of a master plan for building the Integrated Map of Underground Spaces" that took place from

*Corresponding author: e-mail: wkddydrn@kict.re.kr
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December 2014 to April 2015 and is still underway. In the past, underground facilities were managed on the basis of two-dimensional (2D) maps. Unfortunately, 2D maps lack pipe diameter and depth values and are occasionally inaccurate in location provisions. Furthermore, it is nearly impossible to distinguish between various types of overlapping pipelines.(1,2)

To address this problem, the underground information utilization support center has been conducting research on the establishment of an automatic update system for the Integrated Map of Underground Spaces as part of promoting its practical application. To establish an automatic update system for the integrated map of underground spaces based on the submitted updated information, it is essential that the collected data be a standardized database. Therefore, we designed a mapping table and a standard database for the construction completion report (updated information) submission of underground utilities and presented a framework for implementing 3D modeling processing and update automation.

1.2 Literature review

In this literature review of Korean and international studies, the mainstream research on 3D underground utility modeling was confirmed as probabilistic 3D pipeline models aimed at minimizing the accuracy errors of 2D data models, such as missing data for depth and diameter values and discrepancies in data acquisition methods (e.g., mixed use of relative and absolute position coordinates and non-use of vertical datum). It was also found that the 3D data model concept of application domain expansion (CityGML Utility Network ADE) was utilized to attempt a shift from the fragmentary and uniform 3D object representation of underground utilities to their standard data modeling and application to the 3D management of underground utilities. Table 1 is a list of reviewed literature. (3–13)

Table 1
Literature list.

Author(s)	Title	Date
H. S. Ahn	The development of the object-oriented data structure and 3-D visualization system for the management of underground utilities	1997
Y. Du and S. Zlatanova	An approach for 3D visualization of pipelines. In A. Abdul-Rahman	2006
Y. Du, S. Zlatanova, and X. Liu	Management and 3D visualisation of pipeline networks using DBMS and AEC software	2006
A. Balogun, A. Matori, and D. Lawal	Developing a framework for the 3D visualization of underground petroleum pipelines.	2011
T. Becker, C. Nagel, and T. G. Kolbe	Integrated 3D modeling of multi-utility networks and their interdependencies for critical infrastructure analysis	2011
J. Guerrero, S. Zlatanova, and M. Meijers	3D visualisation of underground pipelines: Best strategy for 3D scene creation	2013
P. Carlo and H. A. James	Advances in 3D modeling of existing subsurface utilities	2014
S. Li, H. Cai, and V. R. Kamat	Uncertainty-aware geospatial system for mapping and visualizing underground utilities	2015
L. L. olde Scholtenhuis, X. den Duijn, and S. Zlatanova	Representing geographical uncertainties of utility location data in 3D	2018
A. Fenais, S. T. Ariaratnam, S. K. Ayer, and N. Smilovsky	Integrating geographic information systems and augmented reality for mapping underground utilities	2019
J. Yan, S. W. Jaw, K. H. Soon, A. Wieser, and G. Schrotter	Towards an underground utilities 3D data model for land administration	2019

1.3. Special act on underground safety management (Underground Safety Act)

The Underground Safety Act was enacted in January 2016 to prevent the harm caused by ground subsidence and ensure public safety by establishing a management system for the safe development and utilization of underground spaces. The revised law came into force in December 2020, which contains 'the obligation to formulate an underground space information accuracy improvement plan', 'reinforces the duty to submit changes in underground spatial information' and 'the application field expansion of the integrated underground spatial map'.(14)

The Underground Safety Act defines the term "underground" as "the regions beneath the surface of the earth intended for development, use, and management". Chapter 6 Article 42 specifies the production of an integrated map of underground spaces and the mandatory submission of updated information.

1.4. Integrated map of underground spaces

The "Integrated Map of Underground Spaces" is defined as "a map containing location information for natural and artificial features in underground spaces and information necessary for the related spatial recognition and decision-making." The integrated map of underground spaces consists of 15 types of core information: six types of underground utility networks (water supply, sewage, telecommunication, heating, electric power, and gas), six types of underground facilities (subways, tunnels, underground shopping malls, underground motorways, underground walkways, and underground parking lots), and three types of geotechnical information (borehole, well casing, and soil test results) (Fig. 1).

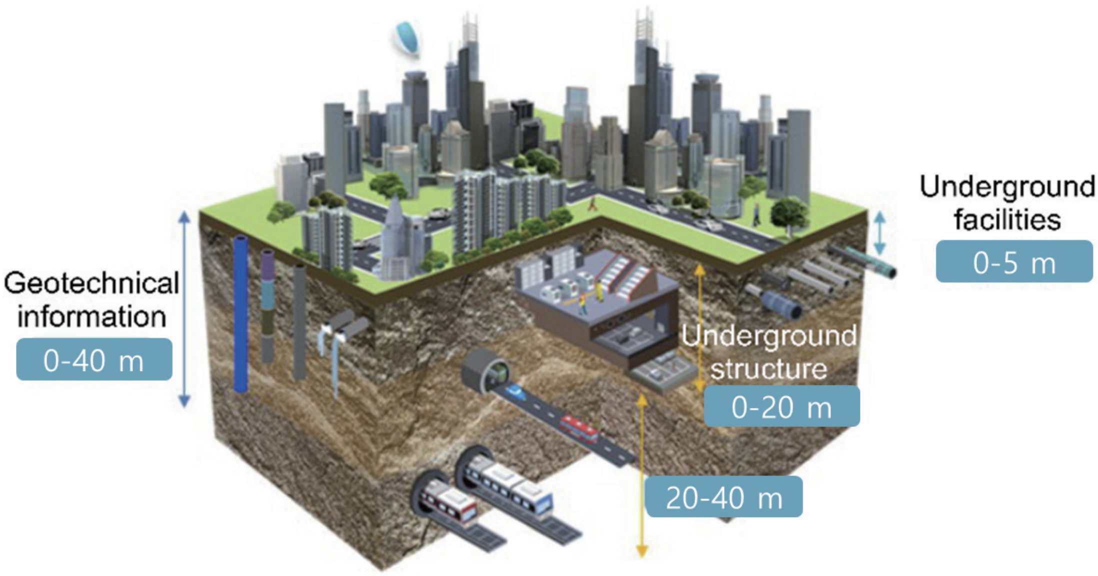

Fig. 1. (Color online) Components of integrated map of underground spaces.

2. Design of Standard Underground Facility Submission Data

2.1 Underground facility management agency database design analysis and mapping table construction

For the submission of construction completion reports of standard design of changing underground facilities, 244 database tables for local government water supply and sewage data, 35 tables from gas pipeline management agencies, two tables (power transmission and power distribution) from power line management agencies, four tables from communication network line management agencies, and 19 tables from heat pipeline management agencies were collected and analyzed. On the basis of the analysis results, mapping tables were designed. When constructing the mapping table, the layer information of each agency responsible for management was used, and the table of the original facility management numbers (codes) maintained at each agency was separately compiled with the field name ORG_IDN to enable their later matching with the utility service of each agency. Table 2 presents a portion of the mapping table.

2.2 Standard database design

The standardized submission of construction completion reports is a prerequisite for the construction of an automatic renewal system for underground facility information. On the basis of the previously conducted structural analysis of management agency databases and mapping table settings, a standard database for construction completion report submissions was designed. The standard database design included three major steps: defining the standard table, defining the standard data code, and preparing the construction completion report classification code. Standard administrative codes (https://www.code.go.kr/index.do) were adapted for legal districts, postcodes, and si/gun/gu codes, and the commonly used National Geographic Information System (NGIS) codes were adapted for geographic feature codes. For water pipelines, twenty-seven geographic feature codes were defined: water supply utility access holes, water supply catchment areas, water supply intake stations, water supply service reservoirs, water supply piezometers, and so forth. For sewages, twenty-seven codes were defined: sewer pipes, drainage connection pipes, sewer holes, storm overflow chambers, outfalls, sewage treatment plants, and so forth. Code definitions for six types of underground facilities

Table 2
Portion of mapping table.

Administrative Dong Code	Original Layer	Original Layer_name	Organ code	Shape type code	Coordinate system code	Standard Layer_name
1100000000	A001_A	Road surface	FAC002	SPA003	COR216	RDL_RDAR_AS
1100000000	A001_L	Boundary line of road	FAC002	SPA002	COR216	RDL_RBLN_LS
1100000000	A004	Crosswalk	FAC002	SPA003	COR216	RDL_PDCR_AS
–	–	–	–.	–	–	–.

were completed using the above method, including 14 electricity codes, five communication network codes, seven heating codes, and nine gas codes. In addition, all underground facility management agencies were given codes to facilitate administration based on the ordering agencies of underground space developer construction completion reports. A few standardized codes are listed in Table 3.

Tables of Standard were designed on the basis of the construction completion reports submitted in standardized codes. A total of 162 tables were defined, including 22 common tables, 57 road tables, 7 provincial water supply tables, 19 water supply tables, 22 sewage tables, 9 electricity tables, 8 gas tables, 6 heating tables, and 4 communication network tables. The existing standard was reviewed to document the table design in compliance with the standard application schema (KS X ISO 19109) and the standard geographic feature listing method (KS X ISO 19110). The standard underground facility construction completion report submission database designed in this study was finalized by collecting and reflecting the opinions of administrators of the underground facility management agencies interviewed online from August 14 to September 29, 2021. Moreover, the designed database was applied to the construction completion report submission system that underground space developers may utilize with the Internet to provide a fast renewal system for integrated underground spatial maps. A quality inspection function was added to monitor compliance with the standards provided.

3. 3D Underground Facility Processing and Partial Renewal Automation Technology Development

3.1 3D underground facility processing automation technology development

A 3D pipeline can be modeled by generating vertical elements from 2D horizontal segments or by calculating the vertical elements.[5,6] Each pipeline depth value obtained as a relative value must be recalculated as an absolute height value.

In this study, we attempted to accurately model underground pipelines by implementing a 3D underground utility processing automation program using an algorithm that automatically calculates the depth and pipe diameter values on the basis of the integrated map of underground space production rules.[19]

'Depth value' is essential for 3D underground utility pipeline modeling. Thus, the 3D underground utility pipeline generator was used when calculating the depth values needed for 3D pipeline modeling. The depth recalculation method was also determined on the basis of the

Table 3
Part of standard code.

Classification code ID	Code classification	Code ID	Code value	Code separation
FTR-001	Geographic feature code	SA001	Waterworks pipe	Waterworks
FTR-001	Geographic feature code	SA100	Waterworks manhole	Waterworks
FTR-001	Geographic feature code	SB001	Sewer pipe	Sewage
–	–	–	–	–

pipeline modeling method (Fig. 2). That is, if a 3D pipeline is modeled from the top point downward, the depth (d) is subtracted from the surface height (H). If a 3D pipeline is modeled at the center point of the pipeline, the depth (d) and 1/2 of the pipe diameter (D) are subtracted from the surface height (H).

The order of priority for the pipe diameter and depth drawn from the operation principles for the creation of integrated underground spatial maps was applied to improve the accuracy of 3D pipeline features. The order is shown in Table 4 as follows: (1) the depth value of the depth layer, (2) the depth value of the pipeline layer, (3) the depth value of the adjacent facilities, and (4) the depth value based on facility legal standards. The average depth of each underground facility was used as the depth value based on the facility legal standards(17) considered for the development of an automatic pipe diameter and depth calculation algorithm. The diameter priority in decreasing order is as follows: (1) pipe diameter if available, (2) adjacent pipe diameter if available, (3) the most common pipe diameter in the district, and (4) the diameter of a general-purpose pipeline if there is a normal pipe diameter value in the pipeline attribute table. Figure 3 shows the pipe depth correction algorithm developed on the basis of the depth priority order specified in the integrated map of the underground space production rules. First, the algorithm searches for all types of pipelines. If there is a depth layer, the attribute value of the depth value field of the depth layer is entered into the pipeline end point. In the case of a sewer pipeline, the start and end point depth values of the sewage layer are assigned. If there is no depth value, the value of the adjacent pipeline (virtual depth value) or the district average depth value is assigned.

Figure 4 shows the pipeline diameter correction algorithm developed according to the integrated map of the underground space production rules. Figure 5 illustrates the visualization of the 3D pipeline model developed by applying the depth and diameter correction algorithms. The illustration on the left does not reflect the real features of the underground pipeline because the same standard depth is applied to the model, whereas the illustration on the right implements a 3D underground pipeline model closest to the real feature by correcting the depth and diameter values using their respective algorithms.

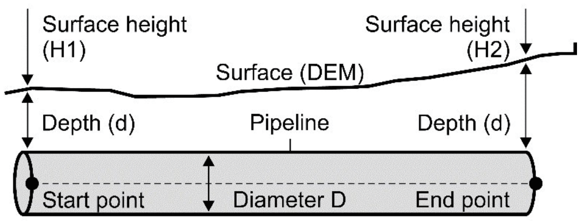

Fig. 2. Recalculation of pipeline depth applied by DEM altitude value. $Z = H - d$ (1), $Z = H - d - D/2$ (2), (Z): depth recalibration value, (H): surface height, (d): depth, (D): pipe diameter.

Table 4
Average depth value in the absence of undetected area and depth data (unit: m).

Service water (wide area)	Sewage	Electric power (distribution)	Gas	Heating	Communication
1.2 (3.0)	2.0	1.5 (5.0)	1.0	1.7	0.7

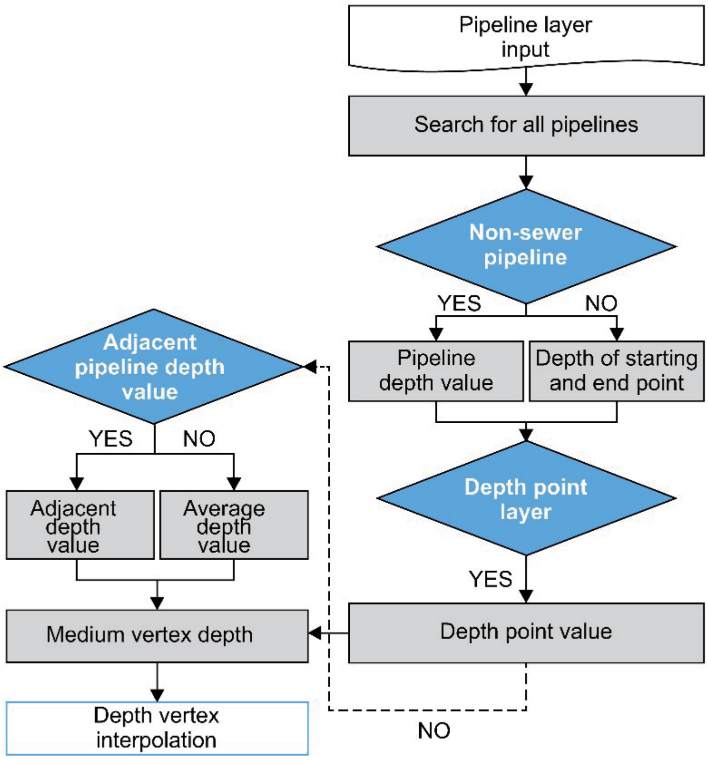

Fig. 3. (Color online) Automatic calculation algorithm for pipe depth.

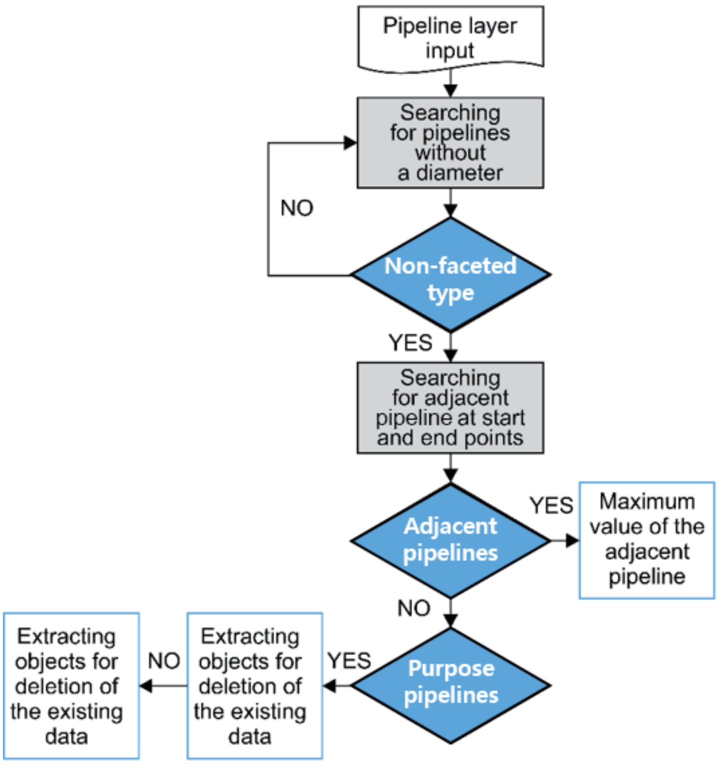

Fig. 4. (Color online) Automatic calculation algorithm for pipe diameter.

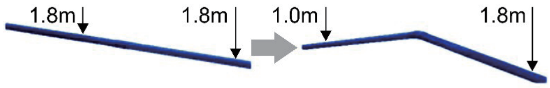

Fig. 5. (Color online) 3D underground utility model applied by automatic calculation algorithm for pipe depth and diameter.

3.2. 3D underground facility renewal automation technology development

The underground utility partial update automation program developed in this study is sequentially implemented, as shown in Fig. 6, using the updated data detection and extraction algorithm, and the 3D processing and update algorithm. The 3D underground utility partial update automation program consists of three sections with their respective functions: updated data extraction function, updated data 3D processing function, and depth interpolation function.

In this study, the water supply pipeline data from Guri City, Gyeonggi-do, South Korea, were used as samples to evaluate the algorithm for detecting, extracting, processing, and updating the changing underground facilities. The change was detected by obtaining the start and end point coordinates of the facilities subject to renewal through cross-searching. Changing facilities were accurately detected as two objects by examining the obtained coordinates for correspondence with existing ones. The change detection algorithm compares the location coordinates of facilities and distinguishes between the new additional update data from the property change update data (Fig. 7) through a property comparison of existing construction data and updated data (Fig. 6). The data subject to renewal are extracted for the generation of 3D models after being transformed into 2D shape files.

The extracted data to be updated generates a 3D shape file combining a 3D model file (Fig. 8). The depth-interpolated data are finally converted into a 3D shape file, and the attribute information is stored in the 3D underground geospatial map database. We developed a partial update automation technology capable of rapidly updating any changes in underground objects. This technology consists of changed object detection and extraction algorithms, updating for the integrated underground spatial map up-to-date. In addition, if an error occurs in the partial update process, an efficient partial update can be performed by implementing a revert function that can start from the previous step instead of restarting from the beginning.

4. Discussion

Currently, renewal systems are nonexistent for integrated underground spatial maps. Therefore, this study is significant for a submission system and an automatic update system based solely on updated construction completion reports. A renewal system for integrated underground spatial map operation was necessary through the early loading of the entire study results, which are made available on the integrated underground spatial map renewal automation system from the integrated underground information system. This automated renewal system for integrated underground spatial maps solves the problem of the low accuracy of current maps. Accurately updated integrated underground spatial maps are applicable in underground safety impact assessments, underground development projects, smart cities, and disaster response.

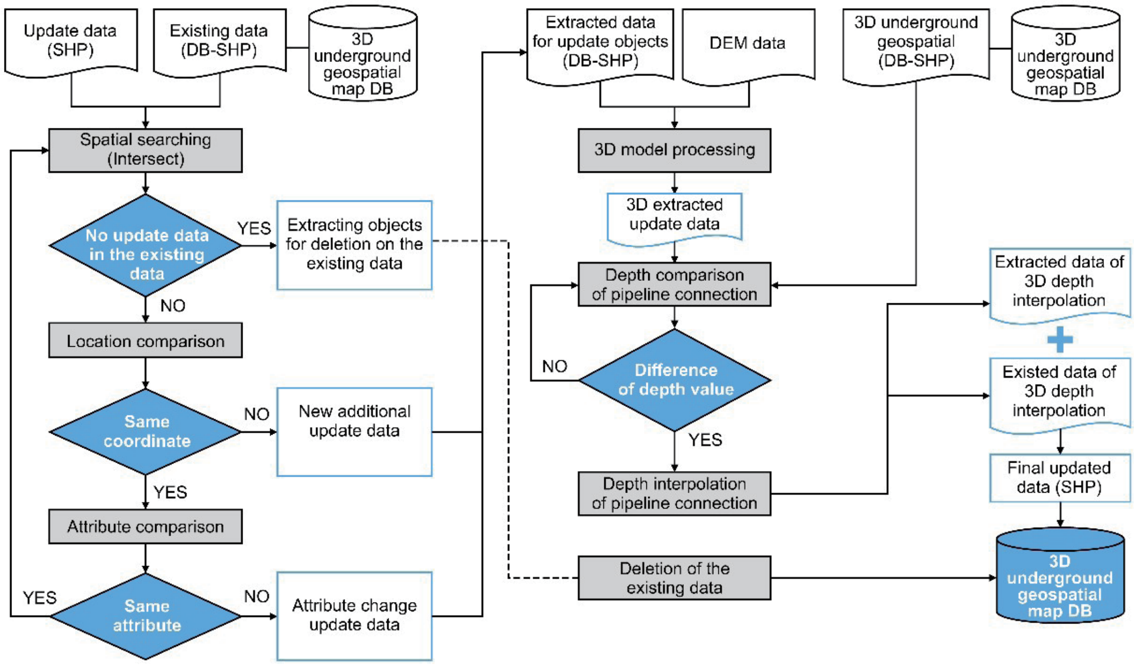

Fig. 6. (Color online) Automated processing and partial update of 3D underground utilities.

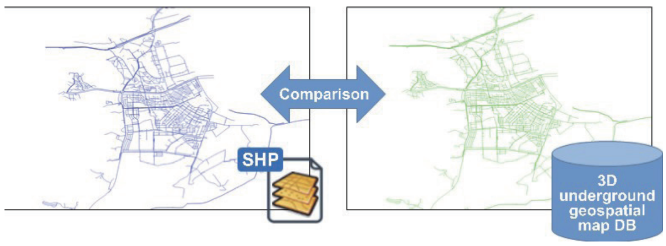

Fig. 7. (Color online) Comparison of partial updated data (left) and existing data (right) of 3D underground geospatial map.

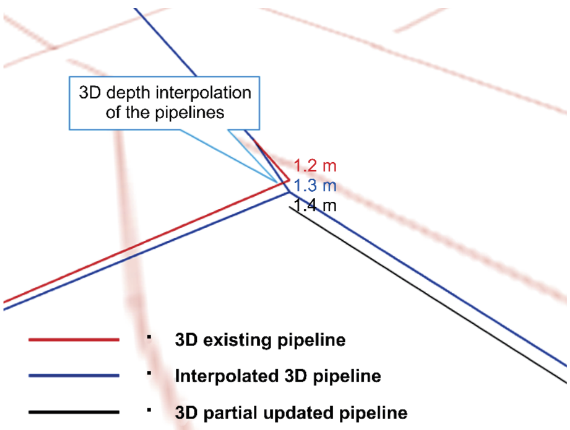

Fig. 8. (Color online) Interpolation with the average depth of the existing and partial updated pipelines. The connection is verified naturally.

5. Conclusions

2D underground facility maps carry the risk of triggering property damage and even casualties during excavation work because inexperienced field workers do not understand the complex underground facility networks, including errors in planar location coordinates and different data acquisition methods. To address this problem, the 3D Underground Geospatial Map ("Integrated Map of Underground Spaces" in the Special Act on Underground Safety Management) project has been carried out since 2015, but it is a time-consuming and expensive undertaking owing to the complicated manual processing of massive data volume. In addition, there was an urgent need to develop a partial update automation methodology to overcome the difficulty of immediately updating every small change in the underground structure. To address this problem, we proposed methods to automatically process and update a 3D underground geospatial map by developing a 3D underground utility model. Annual study results on the automated renewal of integrated underground spatial maps will be reflected in the integrated underground information system that manages and utilizes integrated underground spatial maps. In the future, an automated renewal system on the entire integrated underground spatial map will be realized by continuing geotechnical and underground structure research.

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References

1 Ministry of Land, Infrastructure and Transport: http://www.molit.go.kr/USR/NEWS/m_71/dtl.jsp?lcmspage=1&id=95074554 (accessed April 2023).
2 National IT Industry Promotion Agency: https://www.itfind.or.kr/WZIN/jugidong/1497/file25672-149701.pdf (accessed April 2023).
3 H. S. Ahn: Hanyang University Graduade School (1997).
4 Y. Du and S. Zlatanova: Innovation in 3D Geo Information System, A. Abdul-Rahman, S. Zlatanova, and V. Coors, Eds. (Springer, Cham, 2006) pp. 395–404.
5 A. Balogun, A. Matori, and D. Lawal: Int. J. Chem. Environ. **2** (2011) 135.
6 T. Becker, C. Nagel, and T. G. Kolbe: Advances in 3D Geo-Information Sciences, T. H. Kolbe, G. Köning, and C. Nagel, Eds. (Springer, Berlin and Heidelberg, 2011) pp. 1–20.
7 J. Guerrero, S. Zlatanova, and M. Meijers: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-2/W1 (2013) 139–145.
8 P. Carlo and H. A. James: FL: T and DI Congress, American Society of Civil Engineers (2014) 574–583.
9 S, Li, H. Cai, and V. R. Kamat: Autom. Constr. **53** (2015) 105. https://doi.org/10.1016/j.autcon.2015.03.011
10 L. L. Olde Scholtenhuis, X. den Duijn, and S. Zlatanova: Automation in Construction, **96** (2018) 483. https://doi.org/10.1016/j.autcon.2018.09.012
11 A. Fenais, S. T. Ariaratnam, S. K. Ayer, and N. Smilovsky: Infastructures **4** (2019) 60. https://doi.org/10.3390/infrastructures4040060
12 J. Yan, S. W. Jaw, K. H. Soon, A. Wieser, and G. Schrotter: Remote Sens. **11** (2019) 1957. https://doi.org/10.3390/rs11171957
13 Y. Du, S. Zlatanova, and X. Liu: ISPRS J. Photogramm. Remote Sensing (2006) 395.
14 National Law Information Center: https://www.law.go.kr (accessed April 2023).

About the Authors

Ji Song Ryu received his Ph.D. degree from Anyang University, Korea, in 2020. Since 2020, he has been a research engineer at the Korea Institute of Civil Engineering and Building Technology. His research interests are in spatial information, 3D visualization, Virtual Earth, 3D grid, and underground facility management based on GIS. (ryujisong@kict.re.kr)

Dong Gyun Park received his Ph.D. degree from Pusan National University, Korea, in 2016. He has been a research engineer at the Korea Institute of Civil Engineering and Building Technology. His research interests are in big data and underground facility management based on GIS. (sogone03@kict.re.kr)

Yong Gu Jang received his Ph.D. degree from Pusan National University, Korea, in 1999. Since 2014, he has been a research engineer at the Korea Institute of Civil Engineering and Building Technology. His research interests are in GPS and underground facility management based on GIS. (wkddydrn@kict.re.kr)