Research on the Utilization of Mixed Reality (MR) through the Characteristics of 3D Precise Location

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Key words: Mixed Reality, 3D LiDAR, Spatial Measurement, Virtual Objects, Real-time Monitoring, Construction Technology, Wearable Devices

SUMMARY

Mixed reality (MR), which integrates virtual environments into the real world, has been applied in various industries including architecture, gaming, and design to enhance spatial visualization. By utilizing MR, physical objects can interact with virtual elements, allowing for more advanced applications in fields such as construction, disaster response, and urban infrastructure monitoring. This paper proposes the use of MR for high-precision 3D spatial measurements through the application of LiDAR scanning technology. The proposed system will enhance accuracy in real-time spatial mapping and monitoring in dynamic environments, such as construction sites or complex urban areas. Additionally, wearable devices equipped with MR technology will facilitate technological innovation in spatial measurement and monitoring, offering solutions to various industries such as construction, urban planning, and field-based operations.

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1. INTRODUCTION

In modern industries, spatial information visualization technologies, such as Virtual Reality (VR) and Mixed Reality (MR), are actively utilized across various sectors, including architecture, gaming, and design. In particular, Mixed Reality (MR) integrates virtual reality with the real world, enabling the interaction between physical objects and virtual objects. This technology has brought about innovative changes in numerous industries. Notably, Microsoft's HoloLens, which is based on MR, allows users to view virtual objects in real-time within the physical world and interact with them using gestures and voice recognition. As a result, HoloLens is already being used in the medical, manufacturing, and architectural fields, and corresponding research is also being conducted.

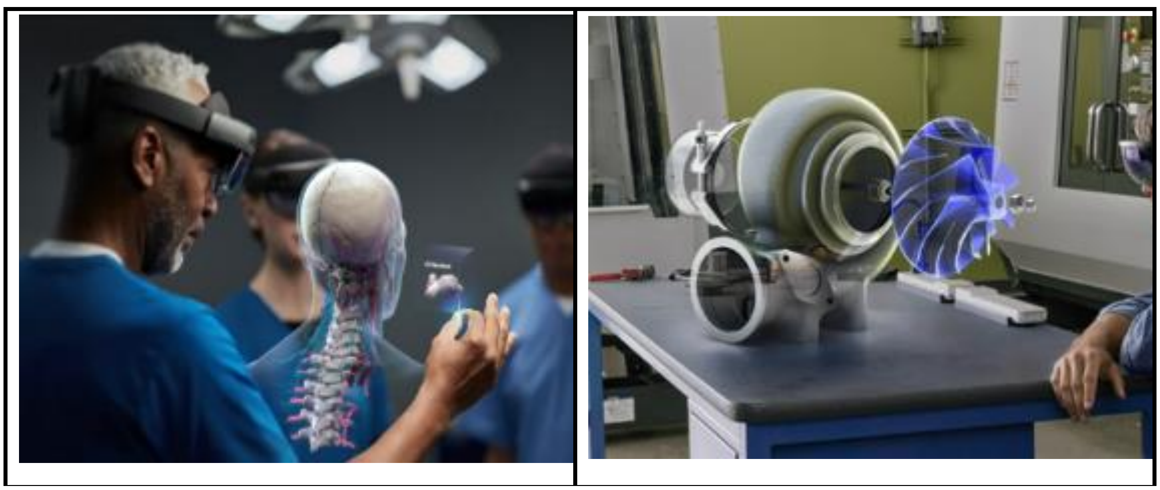

Figure 1 Mixed Reality

Meanwhile, surveying technology plays a critical role in various fields such as construction, excavation, and land planning. However, the surveying technologies primarily applied in real life have spatial limitations, particularly in terms of identifying precise location data within two-dimensional spaces. This has led to the growing need for three-dimensional (3D) surveying technologies. Research utilizing drone imagery and 3D LiDAR scanners to create accurate location data serves as an example of this trend. This study aims to innovate surveying technology and advance the platform by combining geodetic reference points, drone imagery, and 3D LiDAR scanner point clouds to construct 3D point cloud data and apply accurate location information to the LX platform.

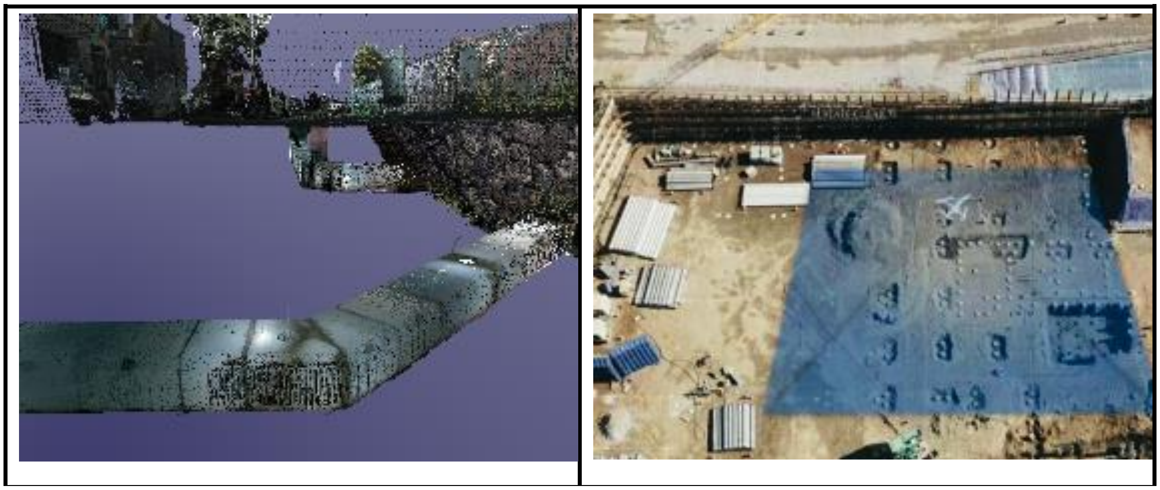

Figure 2 3D rider and Drone

The Korea Land and Geospatial Informatix Corporation (LX) is responsible for supporting the establishment of spatial information systems under Article 112 of the National Spatial Information Basic Act and conducting research on spatial information and cadastral systems. Under the provisions of the Special Act on Underground Safety Management (Amended December 8, 2020) and its Enforcement Decree Articles 33-2 (Designation and Operation of Specialized Agencies) and 43 (Establishment and Operation of the Integrated Underground Information System), LX is designated as the dedicated agency for supporting the establishment of spatial information systems and creating integrated maps of underground structures and facilities. This capability is expected to contribute to innovations in surveying technologies that can enhance productivity and safety in industrial fields.

2. RESEARCH OBJECTIVE

This study aims to focus on the construction of three-dimensional cadastral data through multipurpose cadastral surveying, which involves adding height information to the two-dimensional points and lines used in traditional surveying to represent a more accurate 3D model. The three-dimensional cadastral surveying is described in the cadastral surveying fee guide published by the Ministry of Land, Infrastructure and Transport (MOLIT) and involves adding height (Z), color, texture, and structural information to the existing two-dimensional X and Y cadastral position data, thereby presenting a realistic, high-precision model based on cadastral records. This process applies various factors such as volume coefficient, regional division coefficient, continuous land and collective land perceptual coefficient, and detail coefficient. In areas requiring 3D cadastral data using ground LiDAR equipment, this method is applied for performance reporting. Based on this, the goal is to innovate surveying practices by transitioning from traditional two-dimensional surveying to multipurpose cadastral surveying. Utilizing this approach, the Korea Land and Geospatial Informatix Corporation (LX), as the representative national land information agency of South Korea, aims to establish the foundation of the country's land through cadastral surveying. LX leverages its extensive field experience and cutting-edge technology, covering everything from remote mountainous areas to deep underground, and even islands in the sea, ensuring comprehensive land management.

3. THE NECESSITY OF THREE-DIMENSIONAL PRECISE LOCATION DETERMINATION

3.1 Drone Imagery Data Used Only as Two-Dimensional Reference Maps

With the commercialization of drone technology, which was initially used for military purposes, the use of drones has rapidly developed in the private sector, and today, many aspects of surveying technology incorporate drones. Currently, in construction projects, drone maps are used to create orthophotos for surveying, and these images are analyzed to provide reference materials for performance decisions before surveying. Furthermore, 3D images are generated to identify differences in elevation that are difficult to observe in two-dimensional views, allowing for more realistic object extraction. Although the accuracy of points and lines in surveying can be within the centimeter range, the expectations of the public have also increased, and as a result, there are still limitations in performance decision-making based solely on drone-extracted imagery.

3.2 The Need for Verification of the Location of Underground Structures and Facilities

While drawings of underground structures and facilities exist, modifications after installation, missing drawings due to construction, or the degradation of documents over time can result in discrepancies between the locations shown on the drawings and the actual locations in the field. This has led to numerous accidents, including the destruction of underground facilities during excavation, breakages of sewage pipes, ruptures of heating pipelines, and even fatalities due to such damages. Since underground locations cannot be verified visually, it has become necessary to verify the positions of the facilities and structures based on physical markers such as installed line markers, manholes, electrical reference points, and road surface markings.

3.3 The Need for Accurate Information on Underground and Building Interiors

As South Korea developed in line with industrialization and urbanization, rivers were covered to make way for roads and infrastructure. However, the rapid development in the 1980s focused primarily on expansion, leading to inadequate management of design drawings and construction records, resulting in the loss of many such documents. Consequently, the locations and conditions of current building interiors and underground pipelines remain unknown in many instances. For river facilities, the Ministry of Land, Infrastructure and Transport mandates a regular safety inspection every 1 to 3 years, with a more detailed safety assessment to be performed every 4 to 6 years. However, due to the loss of design documents, there is a lack of information about the current status of pipelines, including the amount and location of runoff pipes. This has delayed the inspection and maintenance of these facilities. Moreover, in buildings, investigations into changes to facility layouts after construction are not conducted, leading to discrepancies between the original design and the actual facilities. This has increasingly hindered rapid rescue or firefighting efforts during emergencies. Therefore, there is a need for three-dimensional data on building interiors and underground conditions.

3.4 The Need for Visualization of Structure Locations

When designing and constructing buildings and structures, perspectives such as bird's-eye views and isometric projections serve as important guides in the design process. However, these visual representations do not always perfectly match the actual completed buildings. This discrepancy often arises because the isometric projections and bird's-eye views cannot account for all the variables between the designer's intentions and real-world constraints. Additionally, structures are often built without considering their impact on the surrounding environment, leading to problems after construction. A representative example of this ongoing debate is the controversy surrounding the Gimpo Royal Tomb Apartments. The Cultural Heritage Administration halted the construction, citing concerns that the high-rise buildings would obstruct the view of Gyeongsan Mountain from the tomb. Although the construction company was accused of violating cultural heritage protection laws for not seeking prior approval, the court ruled in favor of the developers, stating that demolishing the apartment would not yield significant benefits. Furthermore, issues such as the obstruction of views of the Han River and sea, shadow effects on certain apartment floors, and the encroachment of utility poles onto private property have all become social concerns. Using three-dimensional data or simulations through the LX platform can allow such problems to be identified and addressed in advance.

4. RESEARCH AREA AND METHODS

The study on the utilization of mixed reality for three-dimensional precise location determination was conducted in the area from Hallasan University to Noheon Ttranche, a covered stream, and the underground parking lot of the Jeju Regional Headquarters. Three-dimensional surveying was used to construct the current status, which was then applied to the LX platform to plan for the utilization and management of three-dimensional data through the platform.

4.1 Consideration of Methods for Constructing Three-Dimensional Data

To explore methods for constructing three-dimensional data, a comparative analysis was conducted using five approaches: 360-degree panoramic photography, drone imagery, and LiDAR. The following methods were evaluated:

a) Using 360-degree panoramic photography b) Using drone imagery c) Using LiDAR d) Using 360-degree panoramic photography and LiDAR e) Using drone imagery and LiDAR

These five methods were compared in the context of the three-dimensional status construction for the covered stream between Hallasan University and Noheon Ttranche. The comparison focused on data acquisition time, the compatibility of data collection environments, image quality, and location accuracy. As a result, drone imagery combined with LiDAR was selected as the most suitable method.

a) Using 360-degree panoramic photography, the Matterport app can be used to align photos and construct a 3D model. However, since the coordinates or location values for reference points cannot be input, it is not suitable for visualizing status or photo-quality data. b) Drone imagery is not suitable for underground applications, making it unusable in this context. c) LiDAR is essential and must be used, and the study also considered adding color and location information to the status. d) 360-degree panoramic photography can be combined with the blk360 LiDAR and Matterport app to construct a 3D model, but the app does not allow for post-processing of the data, which limits its practical use. e) As a result, drone imagery combined with LiDAR was chosen as the research method. When processing drone imagery, point cloud data obtained from LiDAR can be uploaded and merged with the TIN points from the photos, allowing for the construction of more accurate 3D data than the point cloud location data obtained from drone imagery alone. This method provides more accurate location and coordinate values.

5. RESEARCH RESULTS

5.1 Location Data and Status Acquisition of Underground Structures

In this study, two types of data and status were acquired. First, surface status was obtained using drone imagery and processed with a program to construct a 3D model. Additionally, LiDAR was used to acquire accurate location and status data for underground structures. For the study area, from Hallasan University to Noheon Ttranche, GCP installation and observation, drone imagery collection, and post-processing were carried out to construct the 3D model. The drone was a DJI M300, and due to the proximity to the airport, flight approval was obtained to fly at altitudes below 30 meters, capturing a 1 km^2 radius. A total of 15,977 photos were taken over three days, with oblique imaging. Post-processing took seven days using Bentley's CONTEXTCAPTURE program. The final 3D model was segmented into Cesium tiles for platform upload, taking an additional three days. For underground status and location, control points were set up, and coordinates were obtained using GNSS equipment. Target markers were installed at the control points, and data were collected with a Leica P40 device. The P40 LiDAR device has a data collection radius of over 100 meters; however, for accurate observations, the points were collected within a 30–50 meter radius. As the underground space was dark, lighting was used during data collection. The total length of the covered stream was 1 kilometer, but the interior was divided into two sections. Observations were made along two kilometers, starting from Hallasan University and the

Noheon Reservoir. A total of 164 points within and around the covered stream were surveyed using LiDAR, with data collection taking three days. The point cloud data was processed using Cyclone Register360 to align targets and visuals, and over three days, a total of 3.1 billion points were collected. The final LAS file size was 77GB. For uploading to the platform, point density adjustments were made to obtain the final LAS file.

5.2 Data for the Covered Stream Drainage Pipeline from Hallasan University to Noheon Ttranche

The data collected through drone imagery and LiDAR equipment allow for the identification of 2D coverage stream drainage pipeline status and radius, manhole locations, the distance from the drainage pipeline to the ground, surface pipeline location checks, potential building encroachments, and the location and quantity of inlets to the drainage pipeline.

Figure 3 Left: 2D orthophoto of the covered stream status, Right: 2D orthophoto of the covered stream status

Figures 3 show the linear representation of the covered stream drainage pipeline status in the 2D orthophotos acquired using drone imagery. By overlaying cadastral maps onto the orthophoto, the plot numbers of land parcels passing through the drainage pipeline can be identified, and the areas of potential encroachment can be verified.

	5-10cm	10-30cm	30-50cm
Error Range of River Lines and Survey Points	30point	6point	1point

As seen in the table, errors occurred between the river line and observation points. The covered stream was constructed based on the original river line, but discrepancies appeared when compared to reality. In the case of private land, a 14cm encroachment was observed. The overall route remained unchanged, but significant errors were observed in the curved sections, which could lead to issues during excavation work. Additionally, 2D imagery only reveals flat status, so further on-site verification is required to assess factors such as slope and height differences. Therefore, 3D imagery was constructed using Bentley's ContextCapture.

Figure 4 Construction of 3D model for the covered stream

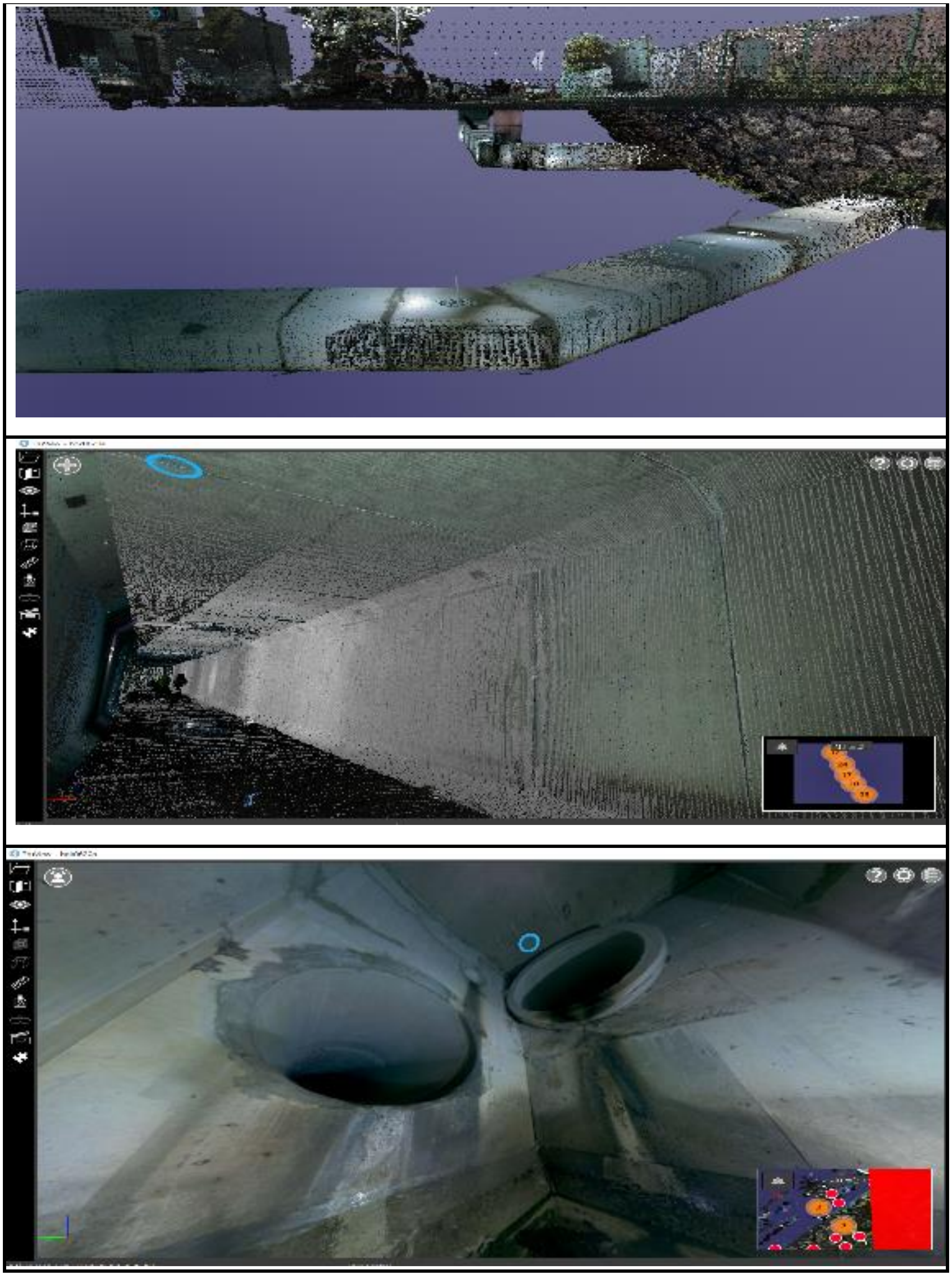

Figure 5 Point cloud data from LiDAR observations, registered in true view

Figures 4 and 5 show the 3D model created using Bentley Context Capture. Moving vehicles and people are automatically removed during processing, leaving only the static status data that is fixed in place. The 3D model allows for a detailed view of the actual site, including variations in elevation and surrounding terrain. It also enables the identification of road slopes, which can help deduce the direction of drainage flow. Point cloud data from LiDAR observations using Leica Register360 is also shown, allowing for visualization of underground drainage pipeline status, inlet locations, manhole positions, road surface height (ground level), leaks, cracks, and specific location height and area data. Furthermore, by using VR devices, the site's status can be examined in greater detail. The data collected through drone imagery and LiDAR has resulted in 2D orthophotos, 2D status lines of the drainage pipeline, 3D models, point cloud data, and panoramic images. However, since these datasets exist as separate files with different viewer and operational programs, there were challenges in utilizing them efficiently. The LX platform was used to address this issue. The LX platform, built on Cesium, processed the 3D models from ContextCapture into Cesium 3D tiles. Point cloud data density was adjusted to 1.3 million points, with a 4% density, reducing the file size to 3GB. While this data was initially planned to be uploaded to the headquarters' Digital Twin, it was instead uploaded to the Digital Twin Cloud by EGIS due to online space limitations.

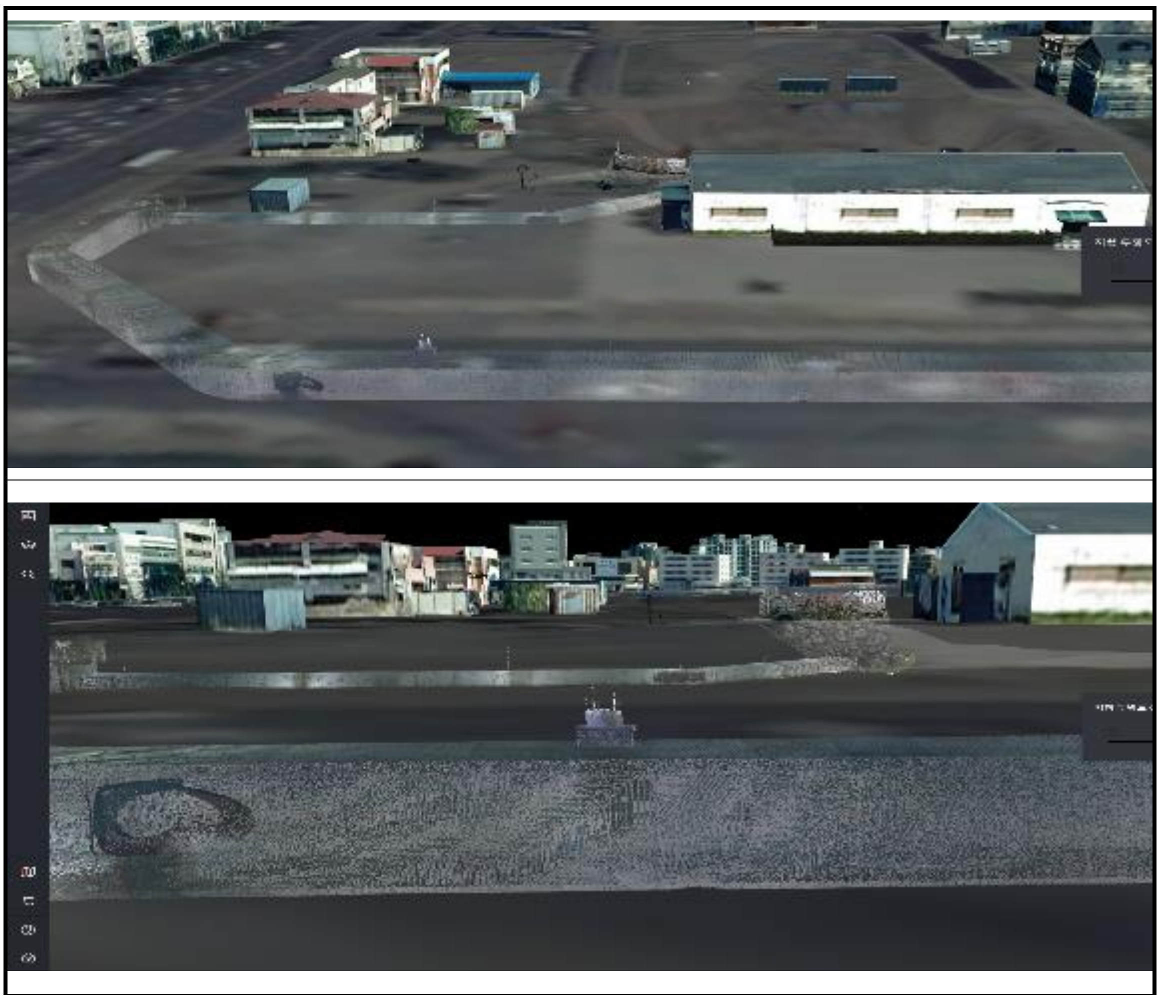

Figure 6 Digital Twin Cloud visualization by EGIS

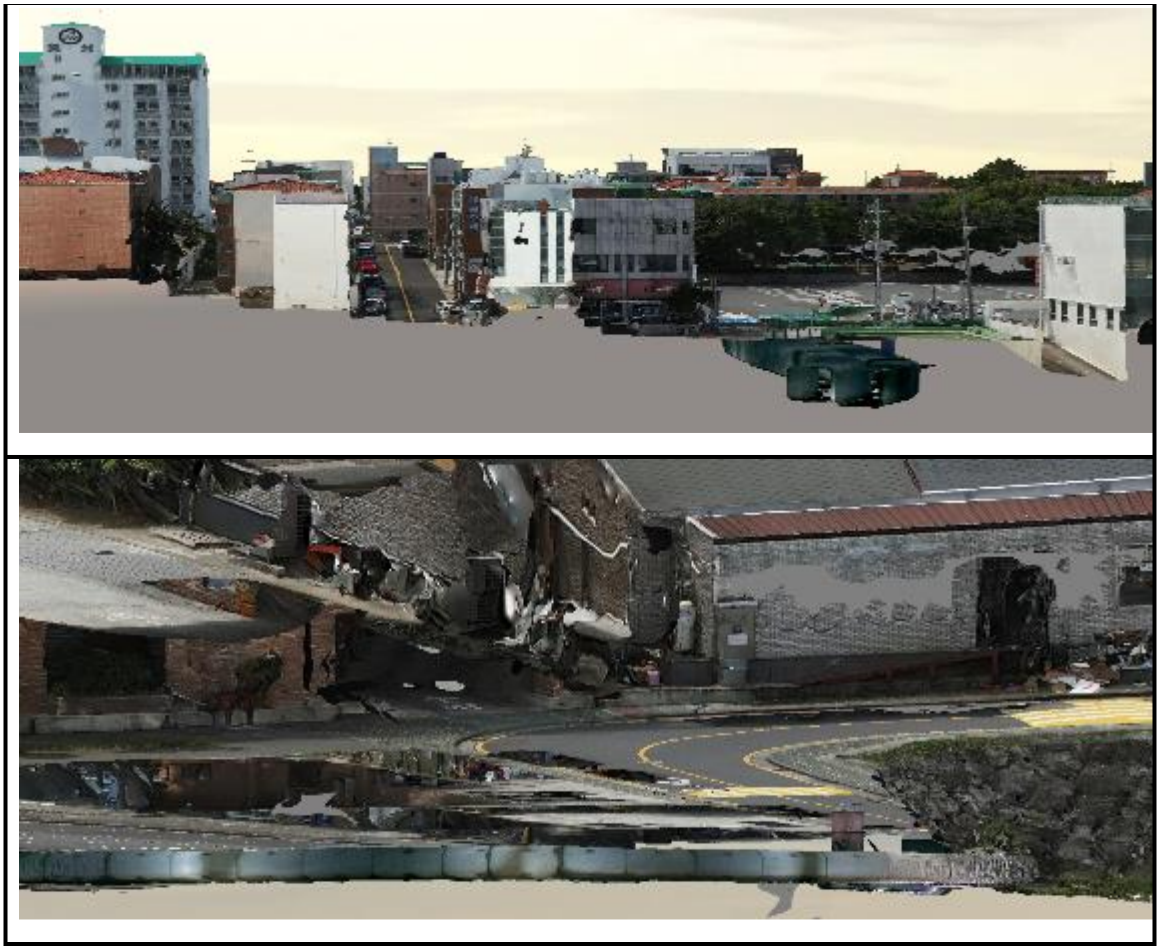

Figure 7,8 Combined point cloud data and drone imagery visualization

Figures 6 to 8 illustrate Digital Twin Cloud visualizations by EGIS and how point cloud data and drone imagery were integrated. The constructed data was uploaded to Trimble's SketchUp to generate models.

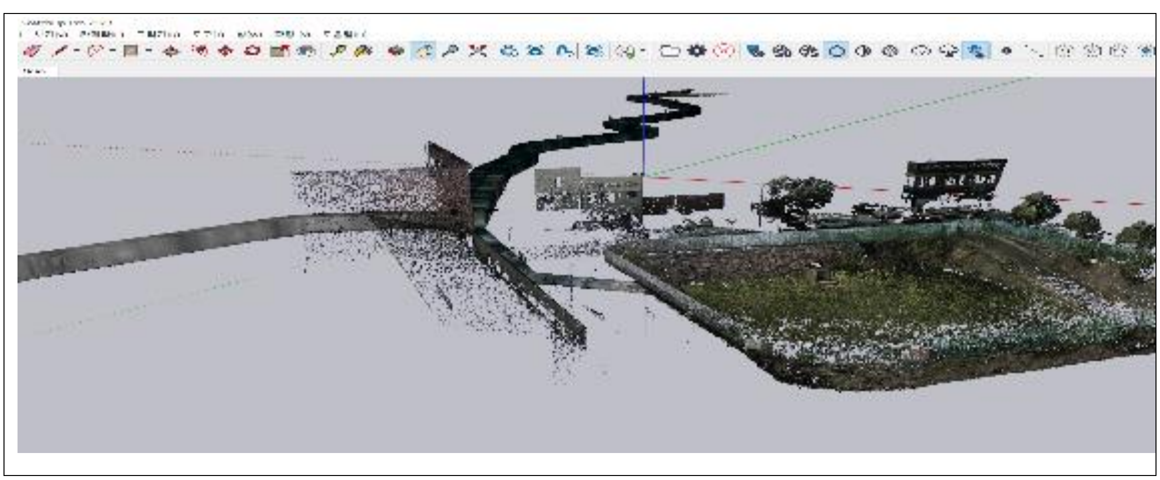

Figure 9 Uploaded point cloud data in Trimble SketchUp

The point cloud data was used to model the shapes of facilities and pipelines, and cadastral maps were converted from DXF files into SketchUp to be overlaid. The model was sent to a cloud server using Trimble Connect via personal ID. The model was then loaded onto the Microsoft HoloLens 2 device. Through this, users can visualize and compare the overlaid cadastral maps with real-world structures, confirming the location of structures and pipelines through QR codes in the field, directly interacting with the digital models.

Figure 10 Left: Trimble Connect QR code capture, Right: HoloLens 2 used for field verification

Figures 10 demonstrate Trimble Connect QR code capture and field verification using HoloLens.

6. APPLICATION METHODS

6.1 Ensuring Stability through Accurate Location Verification of Subsurface Facilities

By directly observing the locations of surface markers, such as track markers, manholes, electrical installation reference points, and road surface markers using GNSS devices or total stations, it is possible to compare the location of these facilities and tracks with the drawings, correcting any errors in the drawings. The corrected drawings can then be verified in the field using mixed reality technology, such as 'HoloLens'. This allows for the simultaneous validation and verification of both the drawings and the actual field conditions, improving the accuracy of the drawings while ensuring that the facility locations align with reality.

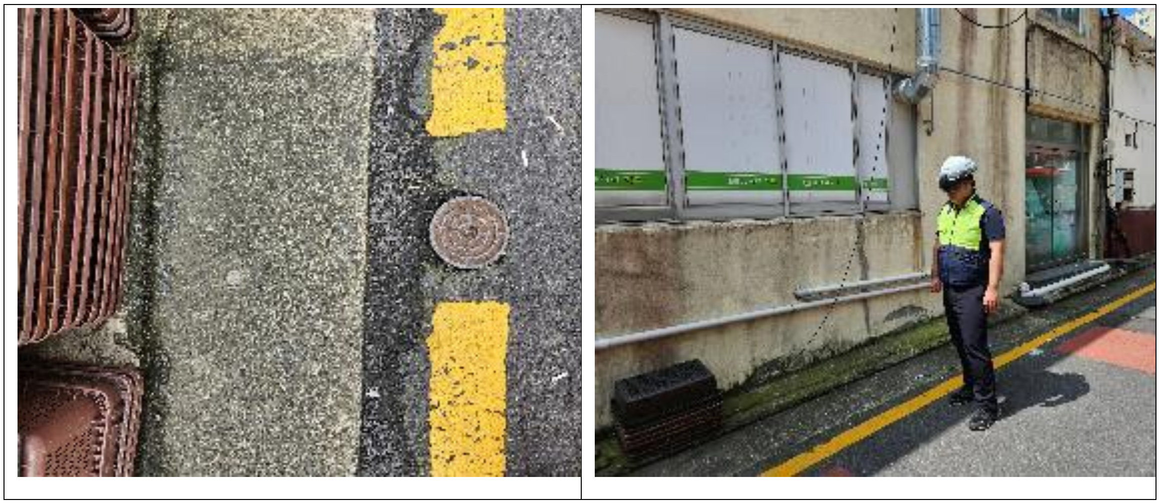

Figure 11 Left: Track markers, manholes, Right: Verifying pipe locations and their real-world counterparts using HoloLens

6.2 Verifying Construction Sites using Mixed Reality

Before the construction of infrastructure in large-scale project sites, virtual city models can be reviewed on-site through HoloLens. This supports decision-making for projects and policies by providing direct visualizations of the construction site. Using precise location data for underground structures and facilities, along with mixed reality technology, organizations can innovate their surveying methods and achieve more efficient spatial data management, including the creation of integrated underground space maps.

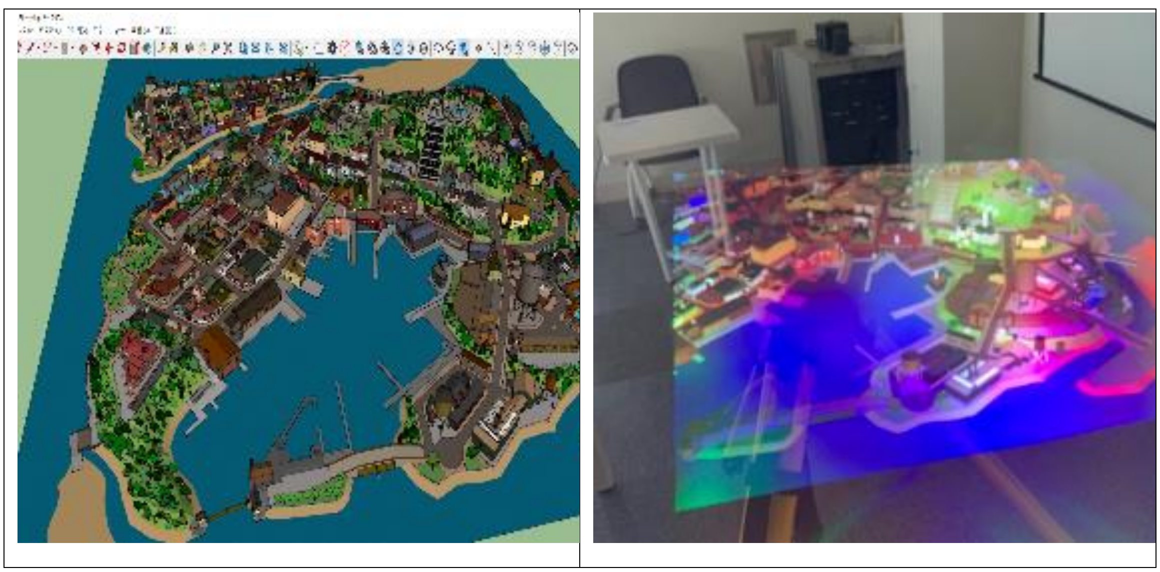

Figure 12 Left: Galmaegi Island SketchUp plan, Right: Verifying the plans through HoloLens

6.3 Increasing Facility Management Efficiency

By maintaining accurate location data of underground facilities such as those in parking lots, underground shopping malls, electrical, fire safety, medical, and water supply systems, it becomes possible to regularly monitor and document changes to these facilities. In cases of emergencies, such as fires or accidents, this data can provide immediate access to the facility's status, enabling rapid and informed responses. This improves disaster preparedness and overall management efficiency.

6.4 Enhancing the Speed of Boundary Point Installation

Boundary point installation, which is crucial in boundary, status, and partitioning tasks, is one of the most challenging aspects of surveying. The difficulty arises because the exact location of boundary points can be unclear to the person performing the installation. Using total stations, the location of poles is determined, and distances to boundary points are measured, leading to the discovery of the boundary points by moving back and forth between the approximate location and the drawing points. However, by using mixed reality, the installer can wear HoloLens and use QR codes to identify their location. They can then move directly to the visible boundary points, significantly reducing the time and labor required to install boundary markers.

7. CONCLUSION

This study highlights the potential of integrating Mixed Reality (MR) technologies with precise three-dimensional (3D) spatial data to revolutionize surveying practices and improve industrial applications. By combining advanced data collection methods, such as drone imagery and LiDAR scanning, with visualization tools like the Microsoft HoloLens, the research demonstrates how these technologies can address existing challenges in construction, underground facility management, and emergency response planning.

The integration of MR and high-precision data enables efficient and intuitive visualization of complex spatial information, fostering more informed decision-making and greater safety during construction and excavation projects. Additionally, MR applications improve the accuracy of facility management and boundary installation, offering practical and scalable solutions for modern industries. This study sets the stage for the widespread adoption of MR technologies across diverse fields, ensuring advancements in productivity, safety, and spatial data utilization.

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BIOGRAPHICAL NOTES

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