GeoACT: Augmented Control Tower using Virtual and Real Geospatial Data

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Abstract. Despite prior efforts to solve urban problems and build smart cities using large-scale urban information, researchers have yet to develop tools for city administrators to easily access a diverse mix of city information. To address this limitation, this article proposes an augmented reality visualization system, GeoACT, which can develop a digital twin to present city information from both macro and micro perspectives. GeoACT employs a 3D virtual city miniature with real and virtual IoT information to provide a macro perspective view, and a 360-degree-video-based visualization technique is used for a micro perspective view. We applied GeoACT to an urban space and demonstrated that it could effectively visualize city information through an augmented reality Head Mounted Display (HMD). Furthermore, GeoACT can be used in urban control centers.

Keywords: Augmented Reality, Smart City, Urban Digital Twin, Virtual City Miniature, Virtual IoT, 360 Video.

1 Introduction

Diverse augmented reality (AR) technologies have thus far been mainly oriented toward entertainment and research, such as Pokemon Go and information visualization. [1, 2]. Researchers focusing on urban space problems and building smart cities have been trying to collect and analyze various large-scale data generated in cities [3, 4]. An example of these attempts is collecting information and setting up the Internet of Things (IoT) in several cities to convert various urban phenomena into

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useful data [5, 6]. In the near future, as a way to visualize this collected information, data visualization using AR will be provided for various city services [7].

However, the development of AR visualization tools for city supervisors is still insufficient despite efforts to spread these smart services [8, 9]. It is difficult for smart city researchers and urban service designers to use existing IoT data because such systems are not equipped to collect and send data in real time. Furthermore, sometimes it is difficult to obtain permissions to access IoT data from other organizations even if the IoT system is equipped.

To address the aforementioned limitations of IoT data, this paper presents the design of city services using virtual IoT (VI) for creating an urban digital twin (UDT) without real IoT (RI) support in the digital twin (DT) production process. Using VI based on RI datasets has the advantages of freely designing and simulating services in the early stages of DT development. Additionally, using VI allows the design of smart services to be provided to citizens at low cost by calculating the amount of data and implementing visualization without the RI [10, 11].

In this article, we propose a GeoACT system that employs a virtual city miniature using VI as a method of overcoming the difficulty and time delay in the development of AR digital twins of a city using 3D geographic maps. A virtual city miniature consists of three layers in the early development: IoT system, cloud system, and DT entailing AR technologies. These layers are constructed using VI in the early development stage when there is no RI, and the virtual simulation data of the VI are employed to facilitate the development with a data structure similar to that of RI, without a development time delay. Furthermore, with respect to DTs developed for the simulation of environmental information using VI, the VI domain is replaced by RI after the RI is equipped. Hence, real data are applied to DTs without time delay in development.

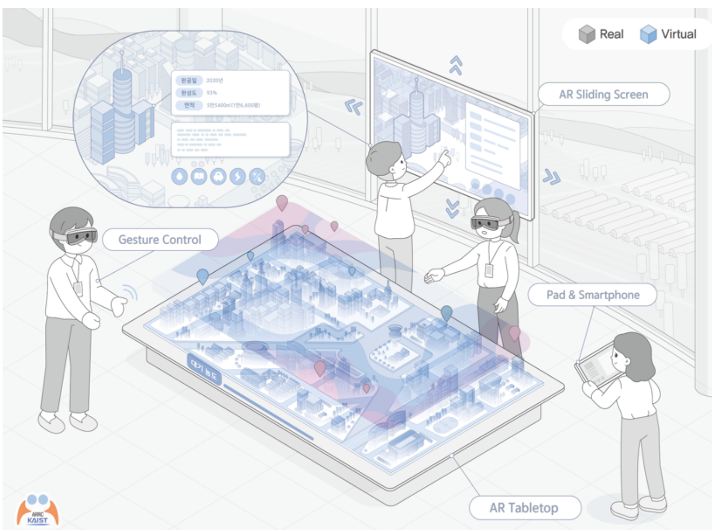


Fig. 1. Concept of GeoACT.

GeoACT aims to be used as a control tower tool for administrators controlling smart cities to understand city information and make decisions quickly. Therefore, it is designed to provide information visualization that allows city administrators to confirm city status information at a glance and visualization via movement to a connected space after determining the point of interest (POI) [12].

In addition to visualizing from a macro perspective with 3D city miniatures, we adopt 360-degree video visualization techniques to represent the micro perspective. 360 video-based visualization shows first person perspective, which shows more detail on urban structures with realistic expression [13]. Furthermore, the system structure of a virtual city miniature is examined in detail.

Fig. 1 shows the concept of the GeoACT system with an example of the use cases at a city control tower. Several city administrators watch the city information visualized and provided in GeoACT's virtual city miniature in the central hall of the control tower simultaneously, using mobile devices and AR head-mounted displays (HMDs). Here, one of the administrators is viewing information on a building being built in a smart city through a glasses-type device that supports gesture control.

The final objective of GeoACT is to improve parts of smart city services that are vital. i.e., life, work, play, and management. In this study, we present DTs for cities, which can provide useful information for the day-to-day lives of citizens, efficient collaboration in the work place, entertainment in the urban space, and the management of city problems that are difficult to recognize. Fig. 2 shows the concept of smart city services based on GeoACT through hierarchical levels. In GeoACT, a DT is constructed in the real world and consists of virtual city miniature, VI data, RI data, a data platform, and AR visualization.

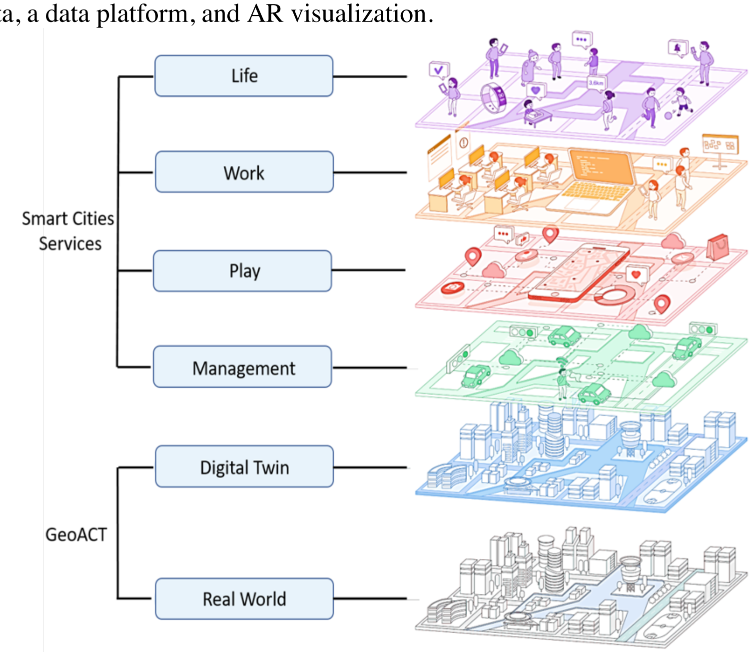


Fig. 2. GeoACT in smart cities as a DT system.

The contributions of this paper are summarized as follows:

- Adoption of virtual IoT in regard to virtual city miniatures for city information visualization.
- Creation of a DT supporting macro- and micro-perspective views.
- Support for 360-degree visualization of IoT data and object tracking for IoT generation from 360-degree streaming media data.

In the next sections, this article presents the related work, architecture and design of the system, implementation, and conclusion.

2 Related Works

The designers and developers of smart city services have been approaching urban issues from the macro and micro perspectives and working continuously to create an urban management ecosystem [14, 15]. They also continued to develop urban DTs to achieve the desired outcomes [16]. This section of the article reviews the creation of an urban DT for a smart city control center using VI, production of an AR-based virtual city miniature, and realistic viewing through 360-degree streaming videos and tabletop interaction.

2.1 Digital Twin Using Public Data

DT technologies are already being used in different systems and industries, such as manufacturing, health care, transportation, aerospace, and construction. Moreover, it is believed that the use of such technologies will proliferate in the coming decades [17]. Ruohomäki et al. produced a 3D-map-based DT using standardized data published through the MySMARTLife project [16]. When we use city data, government open data and standardization formats are useful for DT development. However, the data that can be supported are different, and the range of city services is also diverse because of the varied data policies in a particular country [18]. It is difficult for smart city researchers to design smart services without public data provided by the government, and it is not easy to propose better future city services. We attempted to overcome the data support limitations by using VI in GeoACT and tried to provide service design freedom. In addition, the VI system generates various data from scalar variable values of patterns occurring at a certain point in real-time and provides 3D location information.

2.2 Using Virtual IoT for Smart Services

Bose et al. built a sensor-cloud environment to create a VI environment and applied it to develop tools for visualizing city information. [19]. The sensor-cloud environment's architecture spans multiple infrastructures hosting local and remote resources and can be used for environmental monitoring applications in smart cities.

By contrast, the proposed GeoACT uses the fusion of VI and RI to monitor environmental information and simulate city services. In addition, its VI system was created based on an RI dataset. Notably, it is not just a system design that considers the actual IoT dataset to present a purely virtual environment with software technology.

Andrea et al. proposed a VirIoT platform that enables the virtualization of IoT systems, formed by virtual things and brokers [20]. They used a method in which a mobile phone and broker communicate as clients, and the broker uploads the data back to the cloud system. The method is easy to test, but it is insufficient for generating large amounts of IoT test data. By contrast, we designed GeoACT's virtual IoT system to transmit large amounts of information by generating automatic data on the server. In addition, VI can be useful for small stakeholders whose applications require large-scale IoT infrastructures, who are nevertheless unable to handle infrastructure deployment. GeoACT was designed to help urban managers predict the possibility of success, cost, and development period using VI, which can simulate services that will be applied in the near future. Not only does it support large-capacity IoT data generation.

2.3 Macro Perspective of UDT Using Virtual City Miniature

City monitoring from a macro perspective implies observing the phenomena occurring in a city at a glance [21]. To achieve this, we need a 3D visual map model to observe the city structure as well as the technology to deploy objects and information in an understandable manner [22–24]. Unlike displaying such a general 3D map, an AR device employs a geographic map displayed in the form of a 3D virtual object in real space, which is similar to a giant looking down at a small city [34]. GeoACT provides a 3D city map called a city miniature that was developed to represent the macroscopic city view, and it visualizes city data from cloud services in real time. The city miniature was developed as a control tower concept for non-technical experts monitoring the city, by visualizing and interacting with an AR HMD (i.e., Hololens 2) [25].

2.4 Micro Perspective of UDT using 360 techniques

To manage the city efficiently, it is necessary to observe the city in detail from a micro perspective, and expression using 360-degree videos is one of the tools that can effectively show these details [26, 27]. Cho et al. [28] created a six-degrees-of-freedom (6-DoF) virtual environment, using multiple 360 images. In this environment, a user can freely walk around by using novel view synthesis methods based on the estimated camera pose and point clouds via structure from motion (SfM) [29]. Some studies have shown that 360-degree video streaming is an effective tool for providing an immersive experience and a free viewport [30]. In particular, 360-degree video closed-circuit television (CCTV) streaming is promising for surveillance because it has a wider field-of-view covering all surrounding areas of the camera, without blind areas [31]. Some researchers showed that by using post-processing, 360-degree video streaming can support functions other than only streaming videos. Rhee showed that 3D virtual objects can be seamlessly composited on 360-degree streaming videos [13], and Yang et al. [32] presented 360-degree videos that can generate person localization data by proposing a multi-person localization and tracking algorithm for 360-degree videos. We adopted the 360 technique from the aforementioned studies because it can support a sophisticated monitoring function from a micro-perspective. GeoACT employs a 360 streaming function as well as IoT visualization in 360-degree videos and IoT generation from 360-degree videos. One of the features of this study is that the image data input from the 360 camera is not only used for obtaining the output but can also serve as a sensor for generating IoT data.

3 Architecture and Design

The GeoACT architecture consists of three layers of the system: IoT system, cloud system, and DT, which are used for operating control towers to monitor the urban spaces. The IoT layer has an RI system and a VI system. The RI system is based on a web service in which RI data are created and collected from the real world. The VI system generates simulated data based on RI datasets using a game engine and transmits them to the data platform. In the cloud system layer, the data generated in the IoT system layer are managed, processed, and connected so that they can be transmitted efficiently into the DT layer. In the DT layer, the data transmitted from the data platform are controlled through a tabletop and visualized through the AR HMD. Fig. 3 depicts the relations and connections between the layers of GeoACT. We describe the details of five subsystems that comprise the GeoACT system in the following subsections.

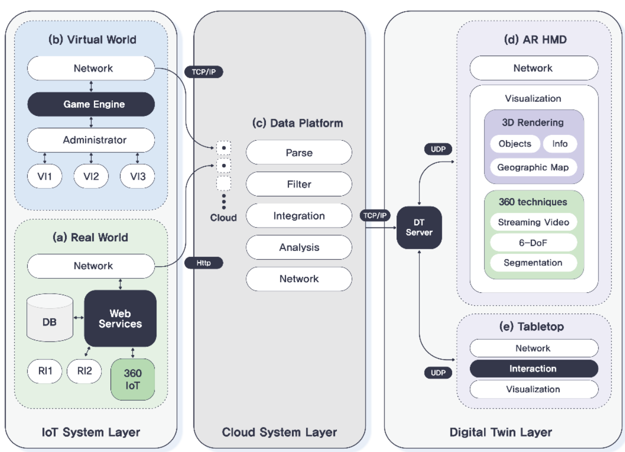


Fig. 3. Architecture and Design of GeoACT.

3.1 Real IoT server system

Fig. 4 illustrates the real-world part in the system architecture of GeoACT; this part collects IoT data from companies and institutions in various urban spaces. The web services collect and process multiple types of datasets such as geo-location, IoT sensing, human sensing, and authoring [33]. Then, the last data are converted to the JSON[1] format and transmitted to the data platform through several processes and modules such as data storage, JSON parsing, and a TCP[2] network module.

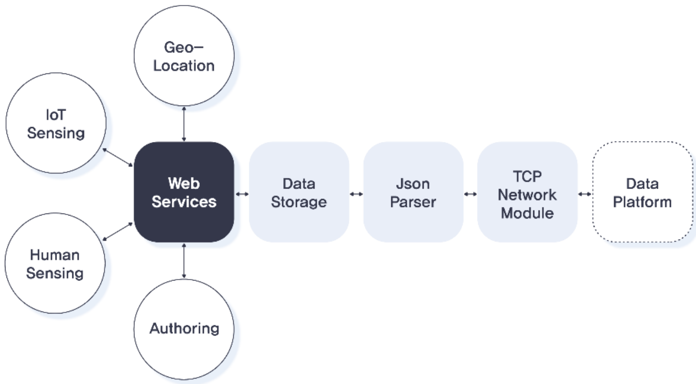


Fig. 4. Components of RI system

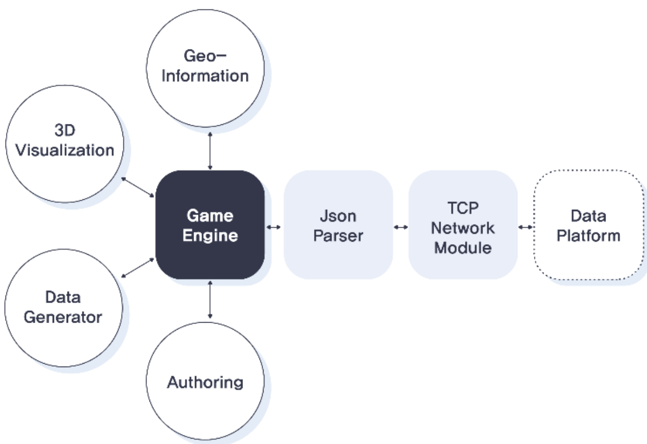


Fig. 5. Components of VI system

[1] JSON: JavaScript Object Notation https://en.wikipedia.org/wiki/JSON
[2] TCP: Transmission Control Protocol
https://en.wikipedia.org/wiki/Transmission_Control_Protocol

3.2 Virtual IoT Server system

This system is presented as part (b) in Fig. 3, the system architecture of GeoACT, and it generates VI data through the self-routine of the server. Fig. 5 shows the relationship among the components; notably, geo-information data, recorded environmental data, and authoring data are combined on a 3D geographical map through a game engine [15]. Then, the simulated data are converted to the JSON format to facilitate data interpretation. Finally, the data are transmitted to the data platform.

3.3 Data platform system

In the data platform area of the cloud system layer, the system receives heterogeneous structured data obtained from RI and VI, as shown in part (c) of Fig. 3. For RI data transmission, the data platform uses the HTTP network, which is easily accessible to web services, to access the IoT data system constructed from diverse organizations and institutions. The VI data are transmitted by TCP[2]/IP, which is a low-level network protocol and is suitable for serial data transmission through sustaining connections. The data platform area of GeoACT plays a vital role in integrating the data generated from VI and RI through multiple processes such as parsing, filtering, and analysis.

3.4 AR Visualization system

Fig. 6 shows the components of the AR visualization system that browses the urban space with an AR HMD, such as Hololens 2. The visualization contents are transmitted from a UDP[3] network module that is compatible with Hololens 2, thereby establishing wireless communication and a quick response time.

In addition, the UDT server relays the network packets generated for control from the tabletop in the interaction area. Then, the AR map of the 3D city miniature synchronizes the position and zoom-in/out with the screen on the tabletop system and visualizes the objects on the AR map, such as buildings, vehicles, notices/event boards, and graphs.

Furthermore, we use a 360-degree visualization technique to present a micro perspective with a first-person view in the urban city miniature. A virtual space was constructed using several captured 360 images, and a 6-DoF technique was applied to freely walk through the area and experience urban space based on real images. Three hundred- and 360-degree video streaming support the monitoring of urban space in detail with a realistic view in real time. The 360-degree visualization technique not only shows the streaming video, but also visualizes IoT data on objects by recognizing their position in 360 videos.

[3] UDP: User Datagram Protocol
https://en.wikipedia.org/wiki/User_Datagram_Protocol

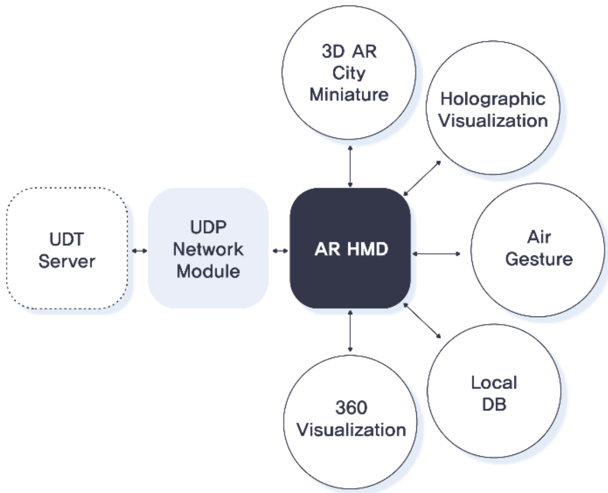


Fig. 6. Components of AR visualization system

Based on 360-degree video streaming data, computer-vision-based scene understanding techniques, such as semantic segmentation, object tracking, and object retrieval, can generate IoT data such as pedestrian and vehicle geopositions. The generated IoT data are visualized in the AR map of the miniature city as points or 3D models.

3.5 Interaction system

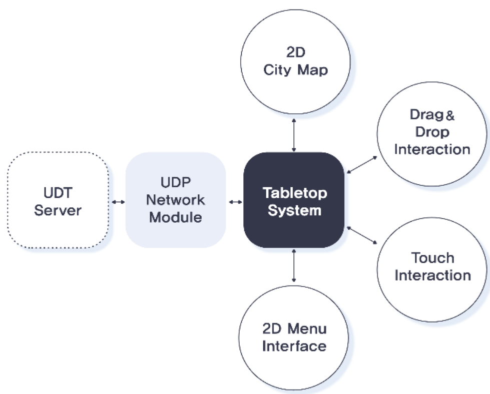


Fig. 7. Components of interaction system

Fig. 7 shows the components of the interaction system from part (e) of Fig. 3; this system is used by the administrators in the control tower to slide and zoom in/out the map of a specific location in the city miniature in GeoACT, and to select and trace one object. Both the AR HMD and tabletop system support the same functions, such as drag-and-drop and selection. The 2D menu of the tabletop is used for selecting specific objects that the view of the AR HMD keeps on tracking, which is especially helpful to show certain objects out of the view of the AR HMD.

4 Implementation

We propose the GeoACT system based on the architecture and design discussed in (Chapter 3) and developed the system by implementing multiple components (Fig. 8) for urban space. GeoACT deals with real-world information, which consists of time-based vehicle movement geolocation data generated from GPS, building energy consumption data, and pedestrian and vehicle movement data generated from 360 streaming videos. The system area of GeoACT that makes up the virtual world generates VI data as vehicle movement simulation data by using a game engine.

The cloud system receives the RI and VI data and transmits them to the UDT server after post-processing. The tabletop system is used to operate the 2D map that is synchronized with the AR HMD through UDP networks. The AR HMD provides a visualization function that shows real and virtual IoT data on 3D city miniatures and directly manipulates the objects through air gestures supported by an AR HMD. In this section, we describe the details of the implementation with two types of applications that are representative of micro and macro perspective views in urban spaces.

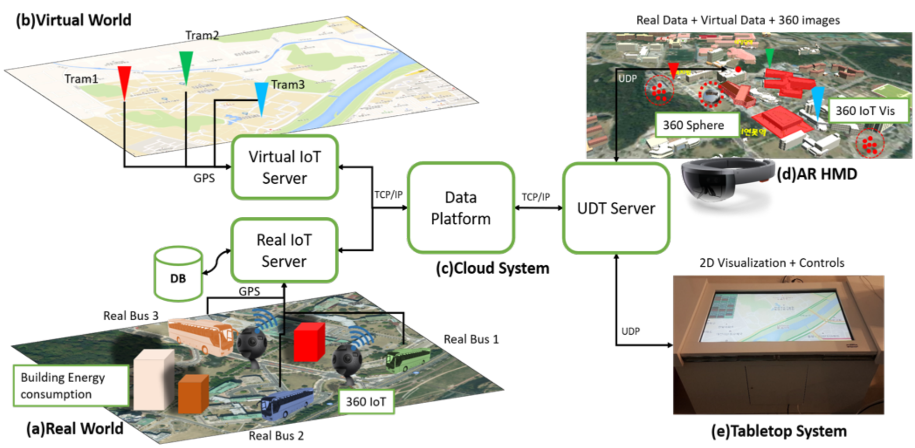


Fig. 8. Overview of the GeoACT implementation

4.1 3D City Map for Macro-Perspective Visualization

The AR city miniature part of GeoACT was developed to monitor the urban space from a macro perspective [34, 35] and view multiple heterogeneous IoT data [36]. We adopted this approach and proposed an AR city miniature as a macro-perspective view with 3D models. The IoT information such as vehicle movement and building energy consumption are visualized on the AR city miniature. Additionally, graphs of IoT analysis information are also visualized over the AR city miniature. Furthermore, GeoACT visualizes object geolocation information, which is generated by using 3D object localization from 360-degree streaming videos.

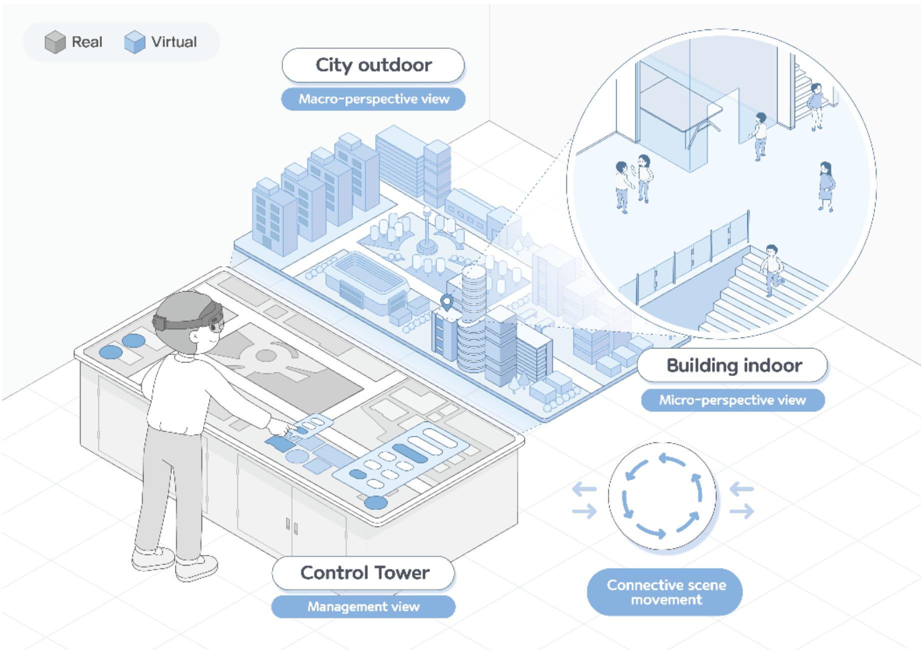


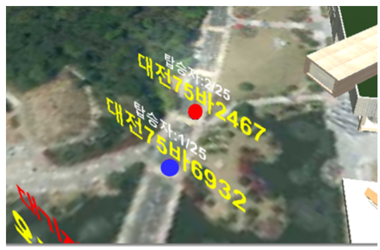
Fig. 9. The concept image of GeoACT system to move for monitoring macro-perspective and micro-perspective views with tabletop interactions

4.1.1 Vehicle Movements

There is a recent service in urban spaces that provides the arrival time of public buses at the nearest bus stations. However, information regarding the number of passengers on the bus is not provided in real time. If information about the number of passengers can be obtained via IoT devices, when one bus is occupied, people can look for other buses/public transportations.

However, the data generated by the RI server is transmitted at one-minute intervals and the type of data is two-dimensional coordinates composed of the longitude and latitude, as shown in Table 1. The RI data are expressed as spheres without directions because it is difficult to show the direction of vehicles due to one-minute intervals that are too long for our real-time system, especially at intersections where the direction is rapidly changed. The number of passengers is generated virtually on the data platform.

Table 1. Real and virtual IoT data structure of vehicle movements

IoT	Parameter	Type	Images
Virtual IoT	Altitude	double	
	Current Passenger	int	
	Max Passenger	int	
	Update Interval	int	
	Action State	int	
Real IoT	ID	int	
	Number	String	
	Vehicle Type	int	
	Latitude	double	
	Longitude	double	
	Date	string	
	Time	string	
	Engine State	bool	

The VI server reproduces simulation data of trams that can be serviced in the future. Altitude data are created with longitude and latitude data to express movement over objects that are not represented on a 2D map, such as bridges and hills. Moreover, the vehicle's position is updated once a second to generate the vehicle direction as a vector by linking the previous position with the current location in the VI area as shown in Table 1.

Table 1 elucidates the data amount and type of tram data, and the data for one tram correspond to approximately 49 bytes. Tram data were transmitted to one thread every 2 s in the initial network test, and the VI server transmitted up to 600 units of data without slowing down. This speed is sufficient when the number of trams in one area is limited.

4.1.2 Building Energy Consumption

GeoACT was created as an AR visualization system that can be used in remote control centers that monitor urban space data [37]. There are several scenarios in which a city traces and manages data in the city control center. For instance, GeoACT can be applied to security data such as CCTV, energy consumption data in urban buildings, and fine dust concentrations in crowded areas [38].

We have provided RI data, namely, the electricity usage of actual city buildings recorded per hour on a daily basis. This data was provided as readable csv files; then, these files were integrated with the VI server in real time. Fig. 9 shows the building energy consumption visualization system implemented in GeoACT.

Fig. 10 (a) shows the graph of the energy consumption when a specific building is selected. Fig. 10 (b) shows the selected building and the power usage status by changing the color. Fig. 10 (c) shows all buildings where real and virtual IoT data are provided, changing the color from white indicating minimum value to red indicating maximum value.

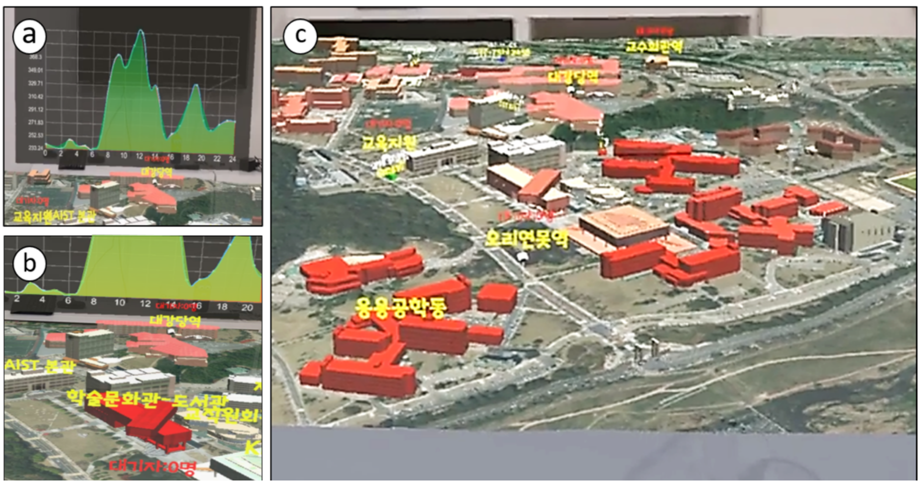


Fig. 10. Representation of building energy consumption

4.2 360-degree Video for Micro-Perspective Visualization

We used 360-degree-video-based visualization to express a micro-perspective view of urban spaces. 360-degree videos support surrounding views at all angles with only one 360 camera. The scenes can be captured with a camera; hence, the cost is reduced. Nevertheless, it provides a more realistic scene with real images. In addition, the scene understanding technique of computer vision can generate IoT information, which is difficult to collect in the IoT sensor method, from 360-degree streaming videos. To this end, we implemented three micro-perspective visualization functions and a function that understands the scenes of 360-degree videos as follows.

- 6-DoF virtual reality to navigate the virtual environment created by multiple 360 images
- 360-degree streaming video that supports real-time surveillance
- IoT data visualization in 360-degree streaming video
- IoT generation from 360-degree streaming video

First, we configured a 6-DoF virtual reality system that supports the user to freely walk around with a free viewpoint in the camera vicinity. Normally, a user cannot be away from a captured camera path, which means that the user has a movement limitation. To overcome this limitation and provide the freedom of movement, we implemented a novel view synthesis method [28] that makes it possible to remove the camera-captured path by synthesizing a novel view image. Finally, we implemented it into Hololens 2 to maximize the walking experience in a virtual environment created by multiple 360 images by synchronizing HMD movements with the viewpoint.

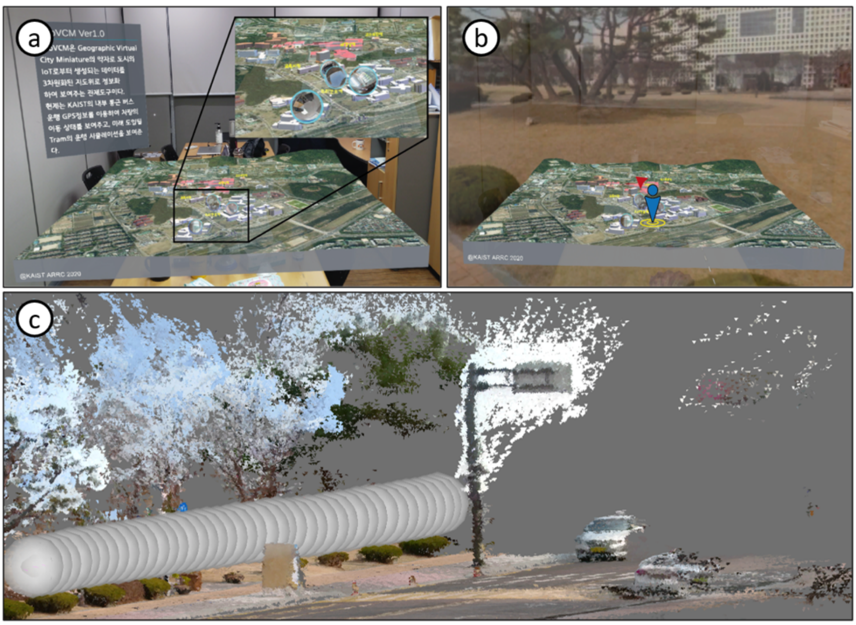


Fig. 11. 360 visualization with AR city miniature in Hololens 2

Fig. 11 (a) shows a user interface (UI) system for moving in a 6-DoF virtual reality scene using a sphere in the GeoACT system. When a sphere with a blue outline is clicked using the AR HMD's air gestures, the scene jumps to the connected 6-DoF scene. Fig. 11 (b) shows that the street-level 6-DoF scene is visualized with a city miniature. The blue icon indicates the position of the scene, and the red arrow indicates the camera rotation of the scene. Fig. 11 (c) shows the multiple gray spheres that have estimated the camera position and rotation information of captured 360 images and point clouds created by integrating the pixels of multiple 360 images. The camera estimation and point cloud generation are processed by the SfM algorithm [29], which is based on the feature matching of images. Even though we do not directly visualize the point clouds to a user, we employ it to provide the freedom of movement by synthesizing novel view images with estimated camera poses.

The 360-degree video streaming function in GeoACT, which shows details with a realistic view, can support real-time surveillance functions such that the city supervisors can monitor urban space points of interest. We implemented the 360 streaming video function into a game engine with a VR streaming player and tested it with Insta 360 pro that supports 4k live streaming. Fig. 12 shows the 360-degree video streaming function implemented in the GeoACT system. The sphere in the city miniature indicates the position of the 360-degree streaming camera, and multiple images represent the frame change of the streaming video over time.

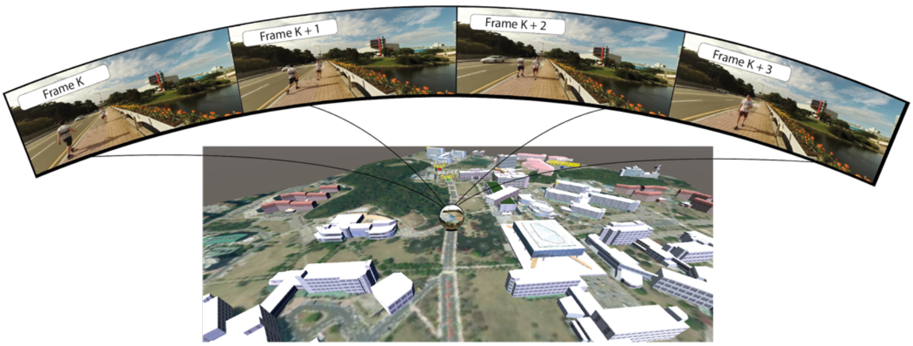


Fig. 12. 360 streaming video that supports real-time surveillance

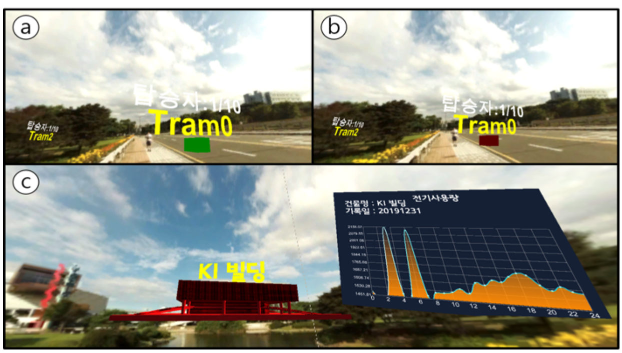


Fig. 13. IoT visualization in the 360-degree streaming video

The IoT visualization function supports a user to watch IoT analysis data on the 360-degree streaming video from a micro perspective, such as a first-person view, by overlaying 3D models, graphs, and text on 360 views. Because we use overlaying methods, the 360 camera should be located at an accurate position in the city miniature. We manually adjusted the camera pose to fit the city miniature. Fig. 13 (a) shows 360 views with a tram stopped at the station, which carries one passenger, and

Fig. 13 (b) shows the tram departed from the station. Fig. 13 (c) shows the energy consumption based on the IoT data for 360 scenes, with the building name, graph, and building 3D model, by changing the color according to the energy consumption fluctuation over time.

A 360-degree streaming video can be used for IoT data generation with computer vision techniques such as object detection, tracking, and pose estimation. We implemented an object 3D detection algorithm [39] that estimates object perspective key points of a 3D bounding box based on a feature pyramid network [40] for accurate real-time 3D object detection from a monocular image. We extracted the bounding box information of each object, including the pedestrians and vehicles, by using the algorithm from a perspective view of a 360 image, and then estimated the object geolocations in the virtual city miniature with depth information generated from a virtual camera manually adjusted to match the real camera pose. Fig. 14 shows a perspective view of a 360 image (a), the bounding box of each object (b), and localized pedestrians and vehicles as 3D cubes (c) in the virtual city miniature.

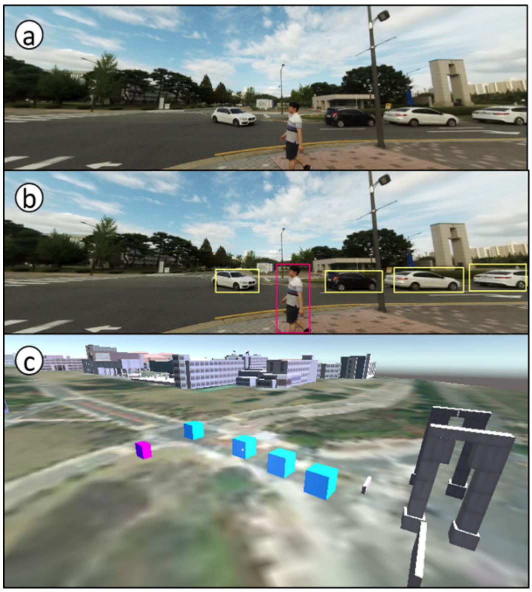


Fig. 14. IoT generation from 360-degree streaming video

4.3 Interactions using tabletop system

GeoACT is a tool designed for city administrators to easily access city information and monitor necessary information in the control center. Therefore, we needed the UI to be easily accessible to non-technical experts. It is necessary to give a comfortable, less tiring, and tactile feeling to those who are not entirely used to air gestures [24, 25]. The interaction system with the tabletop in GeoACT is designed to control the

AR city miniature using the touch and drag-and-drop functions of the tabletop's digital screen.

If the tabletop system connects to the UDT server in Fig. 8, the UDT server transmits the sophisticated data received from the data platform to the tabletop system. The tabletop system represents the 2D information on the screen by combining object lists with the position and state data of vehicles and buildings. The selected item in the 2D menu on the screen is transmitted to the AR city miniature through the UDT server. The AR city miniature presents the city information as a 3D visualization in HoloLens 2 [35].

Fig. 15 (a) shows a user using the touch function of the tabletop system. The geographic map under the 2D menu can be utilized with drag-and-drop for sliding the map, and the 2D map position is synchronized with the location and zoom in/out level with those of the AR city miniature. Fig. 15 (b) shows that a user can select a building directly using the ray-casting function in HoloLens 2.

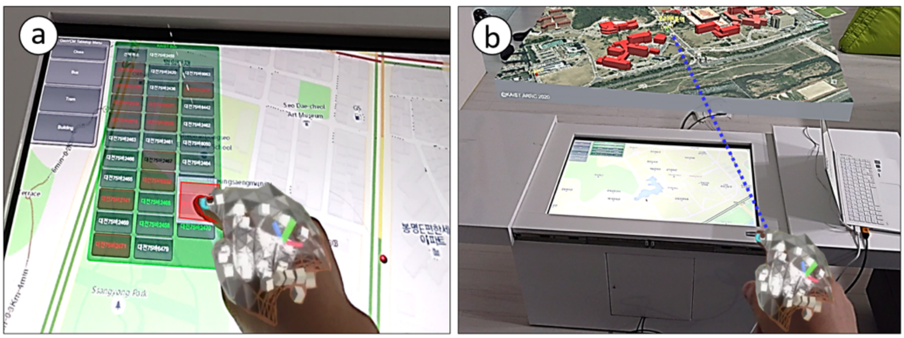


Fig. 15. Tabletop interaction of GeoACT

5 Conclusion

The goal of GeoACT is to develop a UDT of a city for monitoring and simulating city data. VI is used as a substitute for RI in the early stage of development, and it plays a vital role in the pre-design of smart city services. The advantages of GeoACT are as follows.

- Increasing IoT application and development speed: Determining which IoT data should be visualized in the initial development stage of the digital twin of a city is a crucial factor. Moreover, the use of VI can improve the development speed because results can be produced immediately before constructing an RI system.
- Easy validation for heterogeneous IoT: As the VI can be used to produce various IoT data with software, IoT can be validated extensively when developing a data platform. Furthermore, if the VI has the same data structure as the RI, then the VI can be easily replaced when the RI is ready.

- Visualization and simulation of the city environment: If a UDT of a city is obtained using VI, it is possible to simulate IoT data that have not actually occurred in the RI.
- Monitoring to help understand urban circumstances: The ultimate goal of a virtual city miniature is the production of a UDT of a city that facilitates the investigation and understanding of urban circumstances. The environment of the entire city can be browsed by viewing the city at a glance in a 3D city miniature.
- Cost-effectiveness development process of a UDT: Constructing RI in a city involves installing hardware with high costs, which does not guarantee the effectiveness of IoT. Hence, VI can reduce such developmental costs and time.
- Realistic visualization of a micro perspective with 360 visualization techniques: Monitoring street-level and indoor views with realistic 360 visualizations in a 6-DoF virtual environment from a micro perspective is possible. The real-time surveillance system streams 360-degree videos, which in turn provides views of surroundings, thereby helping the administrator consistently watch urban space points of interest. In addition, IoT data can be visualized in the 360-degree videos, enabling data fluctuations to be observed with a realistic view from a micro perspective.
- IoT data generation from 360 streaming videos: 360 streaming videos can be used for generating IoT data, such as pedestrian and vehicle locations on streets, by using a 3D pose estimation algorithm as RI, which can create moving objects in the UDT. This information can be used in diverse applications such as traffic, parking space information, and passenger information analyses.

When the VI is used in a virtual city miniature, a system load test can be conducted as a performance test. Unless RI sensors are constructed and operated, it is usually difficult to simulate how much IoT data are produced [41]. In this case, the VI can support the load test of a server quantitatively.

6 Optimization and Future outlook

The optimization of the VI server's performance and evaluation of the performance data will be reinforced in the future work. The game engine (Unity) plays an essential role in the VI server with regard to processing. Therefore, only considering the network performance without a game process is insufficient.

Suppose the system is designed considering a limited visible area on the map. In this case, the appropriate IoT data that can be applied within the specified map area are limited because the number of IoT sensors in the area is limited. The number of IoT sensors that can be used in an area may vary depending on the IoT sensor type, data amount, and update interval. Most IoT data consist of a small amount of data containing texts and numbers; thus, even large datasets may be employed in the proposed method, considering current communication speeds.

When different types of IoT data are received simultaneously, the data platform server can process multiple datatypes by adding process servers. The network speed that accounts for a large proportion of the total processing time can show different results depending on the IoT structure, number of servers, and the use of a multithreaded system; therefore, separate tests are required in the future.

There is no one-minute delay in the proposed system, and sufficient real-time data processing is possible. However, in the present implementation, there is a one-minute delay in the case of the bus data because the bus corporation's IoT data is updated every minute. Problems arising from these one-minute delays were mentioned in Section 4.1.1. We are considering an interpolation technique that compensates for the delay in information updates due to an RI sensor, even if the DT requires real-time information. We plan to implement this in future research. The route is fixed in the bus movement information so that the interpolation can be easily performed.

Real smart services support the visualization of IoT data on AR 3D maps, but the final goal is to explore the usefulness of services to be provided to the residents of a city through such visualization. For example, the air quality of a city can be visualized for an administrator by using the information received from the IoT, and a service can be provided for the citizens to find optimal paths by avoiding places with poor air quality based on AR devices. In addition, 360-degree video streaming techniques can support diverse remote services such as remote collaboration and virtual visits from remote locations, which can be advantageous in pandemics. Hence, various tests should be performed using GeoACT based on the VI to explore more smart services using IoT for city managers and citizens.

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