AGILE: GIScience Series, 5, 29, 2024. https://doi.org/10.5194/agile-giss-5-29-2024
Proceedings of the 27th AGILE Conference on Geographic Information Science, 4–7 Sept. 2024.
Editors: Alison Heppenstall, Mingshu Wang, Urska Demsar, Rob Lemmens, and Jing Yao.
This contribution underwent peer review based on a full paper submission.

Combination of Augmented Reality and 3D Geographic Information: A User perspective towards Feature-Based Augmented Reality

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Abstract. Augmented Reality (AR) has become widely popular due to its innovative interface and immersive interactions, appealing to both experienced professionals and novice users, making it a versatile technology in various fields. Combining AR with Geographic Information Systems (GIS) has emerged as a valuable approach for enhancing the information available in AR-based applications. In this study, we propose an application framework that integrates Ultra WideBand (UWB) indoor positioning, feature-based 3D GIS, and AR. The feature-based AR scenes were designed to provide enriched information and consider the effects of object occlusion to enhance the user experience. Additionally, a transparent mode allows users to move obstacles based on the 3D features creates an intuitive and adaptable interaction environment. This research demonstrates the effectiveness of the proposed framework in achieving real-time applications such as facility management, surveillance, and object search in indoor environments.

Keywords. Augmented Reality, 3D GIS, Indoor Positioning, UWB, Occlusion

1 Introduction

In recent years, Augmented Reality (AR) has gained global attention due to its innovative interface and the interaction between virtual and real-world elements. Users from different fields have shown interest in this groundbreaking technology (Bazargani et al., 2022), which has the unique capability to overlay virtual elements like 3D models, effects, and animations onto real-world environments captured through a camera. This integration enhances the visual presentation of content by incorporating virtual information or effects into the real-world context (Musliman et al., 2015). For example, the IKEA Place app allows users to use AR to place 3D models of furniture in specific positions, aiding in space planning without the need for physical furniture.

With AR, users can engage with various types of augmented information through a visual interface. Innovative location-based applications have been developed, such as Brata et al.'s (2015) use of AR and positioning technology to provide precise bus information, guiding users to the nearest bus stop with overlaid text and icons in the real-world environment. This is particularly useful for users unfamiliar with the area. Unlike the IKEA app, such an AR-based application would require a built-in mechanism to track users' movement and dynamically determine the displayed information based on their position. In recent years, Geographic Information Systems (GIS) have evolved from two-dimensional (2D) to three-dimensional (3D) representation, leading to significant changes in application development. Feature-based 3D GIS systems have the advantages of accurately capture the spatial position and attribute relationships of various phenomena, facilitating the display, querying, planning, and analysis of geographic information. This comprehensive documentation ensures that each object is associated with its corresponding semantics and meaningful connections to other objects, enabling efficient management of large volumes of 3D data to meet specific application needs (Huang et al., 2016).

The content of AR is primarily derived from real-world scenes captured by a camera and operates within a 3D working environment. By connecting to rendered objects in an AR scene, 3D GIS offer a reliable framework for displaying augmented information at the precise position of real-world objects. This approach can be tailored to present 3D scenes based on user preferences and can also integrate real-time information. This integration leverages the strengths of both technologies, extending the potential for diverse and innovative applications within AR beyond simple visual rendering or virtual environmental displays in 3D GIS.

While many successful AR-based applications for outdoor use rely on Global Navigation Satellite System/Global Positioning System (GNSS/GPS) technology, the accuracy of GNSS/GPS for indoor use is limited and easily disrupted by obstacles such as buildings. Obtaining precise indoor user positioning solely through GNSS/GPS is challenging in practice (Fenais et al., 2019). Ultra WideBand (UWB) is a signal transmission technology known for its wide bandwidth and low energy consumption. UWB's unique capability for indoor positioning lies in its ability to penetrate obstacles like cement walls due to its long signal wavelengths (Alarif et al., 2016). Additionally, UWB signals can coexist with other signals without interference. Its positioning results meet the requirements for indoor use and can provide real-time position information for various applications.

This study proposes a basic framework that integrates UWB indoor positioning, 3D GIS, and AR, leveraging the spatial concepts and diverse information provided by the 3D GIS database. Based on the framework, we propose a feature-based design for AR scenes. A large number of features can be obtained from 3D GIS, and customized service content can be provided based on associated attributes. Four indoor scenes based on the proposed framework was conducted to test the effectiveness of feature-based scenes in achieving various application purposes.

2 Methodology

2.1 Basic research framework

To successfully develop an AR application based on 3D features, the following key tasks need to be fully executed. When utilizing AR technology, it is crucial to have both hardware devices and software interfaces that can display AR content and allow users to interact with the system. It is important to ensure that the presentation of AR information is accurately aligned with the correct geographical position. This requires precise determination of the geospatial information of both users' devices and the phenomena being presented. Additionally, to continuously provide personalized real-time information as users move, a feature-based 3D GIS, a backend server, and a service mechanism are essential. Figure 1 provides a visual representation of the main components and their interactions. The system architecture consists of three primary components: Location service, Server, and 3D GIS and AR Design, represented by gray, blue, and yellow blocks, respectively.

The study's location service uses indoor positioning based on a UWB system at the test site. This technology is similar to GPS and requires four or more base stations with known coordinates in indoor spaces. The hand-held tag's coordinates are determined by the distance between the tags and nearby base stations using the time of arrival algorithm. The positioning result is then transmitted and stored on the UWB server side via the internet. The server continuously tracks the position of all tags, whether static or moving, as well as connects to external servers or databases to request information about 3D objects. The AR Design renders corresponding objects at the correct position based on the retrieved position information and 3D scene content. Users can then visually inspect the scene captured by the camera and view the customized rendered information simultaneously, according to their application needs.

The suggested framework is realized as a web-based application that facilitates the transmission of data between its components over the internet. The UWB tags' positional data is consistently refreshed, and the Server accesses this real-time information through API services. Leveraging this positional data, the server then solicits details about proximate objects from a 3D GIS database. Subsequently, this information is conveyed to the AR Design component in JSON format via the interconnection between the front-end and back-end web pages. The AR Design component then generates a virtual model intended for the user's visual perception, as indicated in section 2.2.

Upon the conclusion of the rendering process, users are able to engage with the device interface in order to retrieve pertinent information. The connectivity between the front-end and back-end components enables the transmission of requests to the 3D GIS database and the subsequent retrieval of response data. This interface provides the capability to manage rendering effects and engage with the user.

The suggested architecture serves as a fundamental framework, which can be employed by any system to develop an AR application based on features. It is adaptable for the creation of applications tailored to specific scenarios to meet user requirements, and also

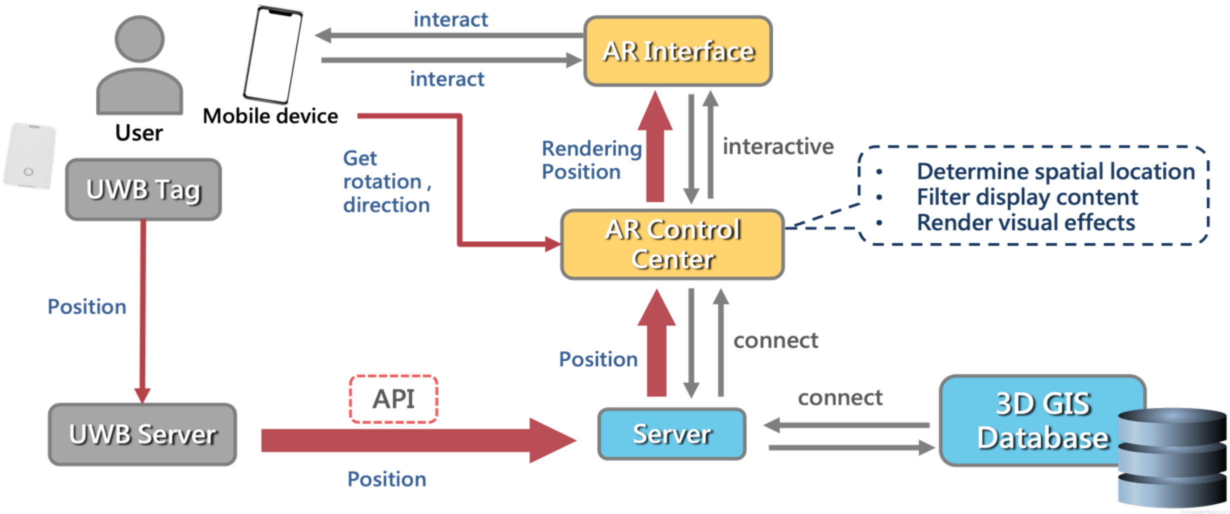


Figure 1. Basic research frame-

allows for the potential expansion of applications developed within this framework in the future.

2.2 Feature-based AR scene design – Users' visual interactions analysis

In the context of Geographic Information Systems (GIS), a three-dimensional feature represents a spatial object in real world. This representation not only facilitates the creation of a scene that closely resembles the real world, but also enables the connection to a database for accessing additional descriptive information. A feature-based GIS database ensures that each object rendered in the AR scene is a distinct entity with specific appearance. This feature-based approach allows for customized presentation and real-time updates based on changes in position and user requirements. The distinctiveness of each feature enables intuitive interaction for users with each object displayed in the interface. Figure 2 illustrates the photographs and the 3D GIS representation of the test site. Similar to users readily request information by clicking individual features in the 3D GIS, such functionality can be also developed in AR applications. In addition to static objects, the position of mobile objects can be continuously updated and monitored by attaching an Ultra-Wideband (UWB) tag. This indicates that the designed AR architecture can be effectively applied to various applications, such as locating missing items, dynamic environment monitoring, facility management, etc.

In practical situations, the unobstructed path of light can result in the obstruction of objects by others. In AR environments, virtual objects are overlaid onto specific positions within the scene (e.g., a digitally rendered computer chair and a potted plant visually superimposed onto a physical desk, as depicted in Figure 3 (a)). The rendering process does not take into account the depth factor, potentially leading to the direct overlay of virtual objects onto real-world objects. Neglecting the influence of occlusion may lead to an inadequate representation (Tian et al., 2015), subsequently impacting users' perception of the actual positions and relative placements of objects.

To ensure that the representation of objects in AR aligns with the overlapping effects of real-world objects and closely resembles a real-world scene, a feature-based AR scene can be utilized. 3D GIS can record the position of objects in the scene and adjust display content to simulate the real-world occlusion of various objects. In the context

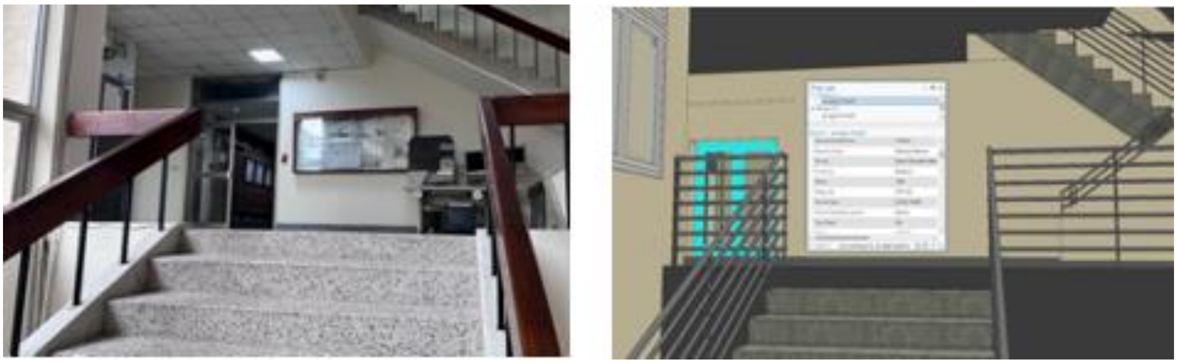


Figure 2. Comparison of photo (a) and 3D GIS (b) of the test site

Figure 3. Occlusion scenario (a) Model of plant and computer chair overlap on desk directly. (b) Displaying partially occluded parts of plant and computer model. (c) Remove desk and left its frame to show model of plant and computer chair to present perspective effect.

of AR scenes, interface design can consider two types of occlusion effects. The first effect aims to replicate real-world scenes by presenting GIS information to mimic occlusion, similar to actual situations. This involves displaying partially nonocclusive portions of objects that are visible to the naked eye and filtering out the occluded parts that should not be shown. The second aspect focuses on moving occluded objects so that objects behind can be observed. Features stored in GIS can serve as the sources of both removing features and rendered objects in this see-through mode (Figure 3(c)).

In line with the aforementioned objectives, this study develops and implements a mechanism for AR occlusion. It integrates GIS information with computer graphics depth calculation technology for occlusion analysis. From a 3D perspective, depth is defined as the distance between an object and the observer, serving as the basis for determining occlusion among objects. The specific technical occlusion process is illustrated in Figure 4 and discussed as follows:

1. Employ positioning technology and sensors on the device to capture the user's position and rotational posture.

2. Compute the distance between the positions of the 3D GIS database's rendering objects and the user's position. Utilize the depth calculation outcome to ascertain if these objects obstruct each other from the user's viewpoint (as denoted by the yellow arrow in Figure 4).

3. If an object is situated at a greater depth from the user and there are obstacles closer to the user, the object should be concealed by the obstacles. Based on the occlusion outcomes, objects are rendered accordingly in the AR interface. One of the effects is realistic occlusion, which renders all the objects in the scene according to their positions to create a lifelike occlusion (Figure 3 (b), desk, chair, and plants rendered based on their actual positions). Another effect is the visually see-through effect, where foreground objects can be individually selected and removed, leaving only their frames to produce a see-through effect (as depicted in Figure 3 (c), where the desk is removed and only the chair and plants are rendered).

The depth calculation outcome is dynamically recalculated as the user's real-time position changes, in order to determine if objects are occluded or not (as indicated by the red arrow in Figure 4).

By utilizing feature-based AR scenes, the illustration can operate more flexibly at the object level. Switching between these two modes allows users' interaction to adapt to different scenarios, while considering occlusion concerns. This ensures that the final interface integrates the advantages of annotation and facilitates rapid access to all information while spatially aligning with the visual effects of the real world.

2.3 Data and Software Availability

The AR frontend web applications mentioned above are written in HTML, and the source code can be accessed through the GitHub repository. The AR applications are created using the AR.js library. GIS data is processed using ArcGIS Pro 3.0. The database is stored and queried using PostgreSQL and PostGIS. The backend server is configured using Node.js and PHP.

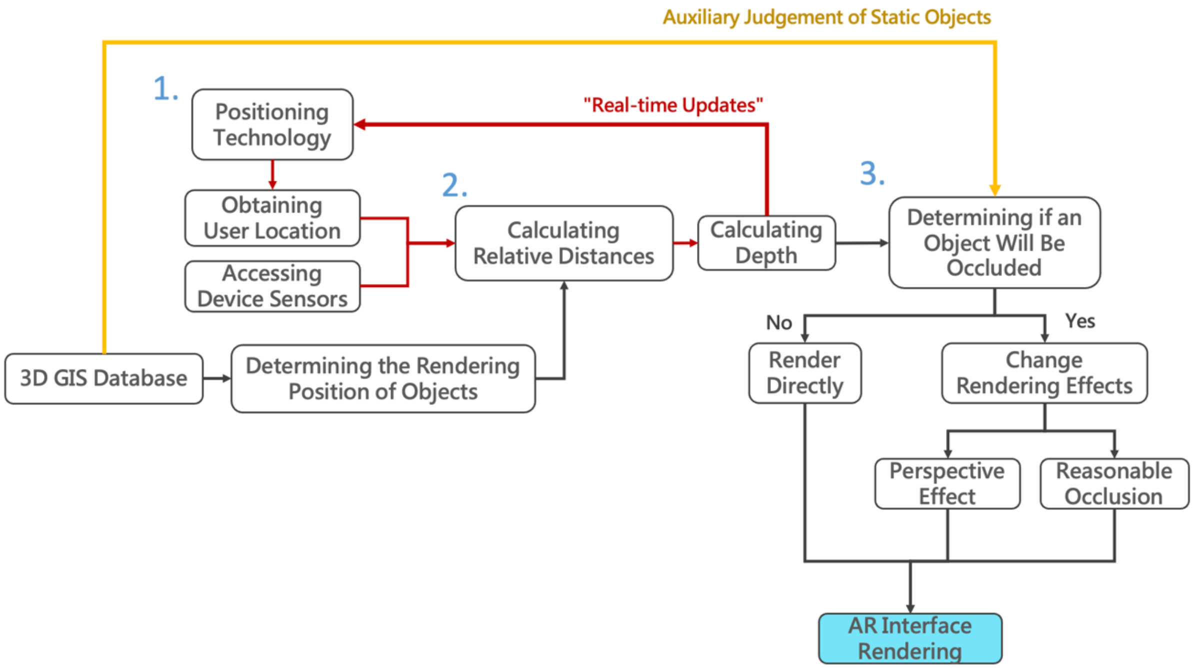


Figure 4. Mechanism for AR occlusion

3 Results

3.1 Test Deployment and Field

Experimental Field

The research is conducted in the second-floor classrooms of the Department of Geomatics at National Cheng Kung University. The department's classrooms are separated by concrete walls, which offers an optimal setting for conducting indoor AR tests. The required feature-based 3D geographic information of the buildings, previously generated in .rvt format using Revit by past researchers, serves as the essential data for the upcoming experiments.

Positioning with UWB

In this study, the indoor positioning tests utilized the UWB system developed by GIPS company (GIPS official website: https://www.gips.com.tw/). This system offers real-time position tracking capabilities through the use of base stations with known coordinates. As individuals carrying the tag move, the system determines the tag's 3D position based on its proximity to the nearby stations. This data is continuously updated, stored in a database, and can be accessed through an API. Fourteen base stations were strategically placed on the first and second floors of the Geomatics Building (refer to Figure 5). The system allows for the simultaneous tracking of multiple tags and presents their positions through a map-based interface. The actual testing demonstrated an accuracy level of approximately 30 centi-meters.

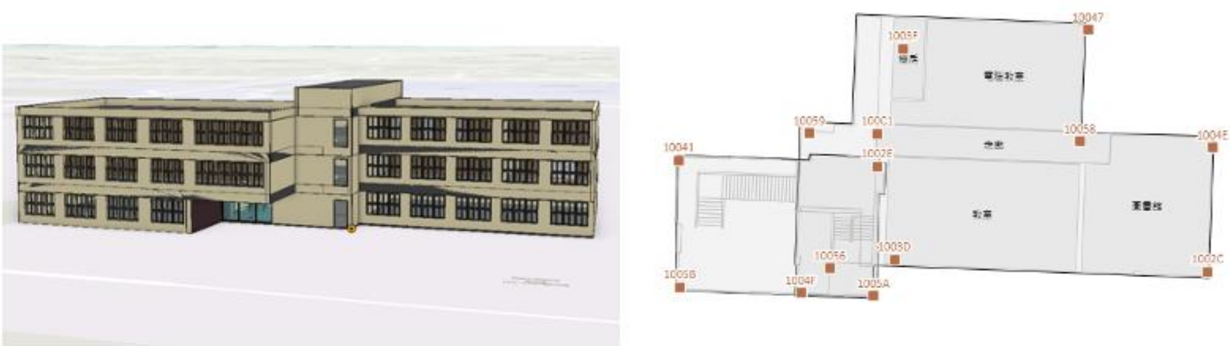


Figure 5. 3D building model and UWB base station distribution floor plan

3.2 Feature-based Augmented Reality Scene

The objects located in the test area are rendered based on the features of 3D GIS. As illustrated in Figure 6 (a) and (b), the AR system displays facilities and text at their respective positions. The interface allows for the linkage and overlay of attribute information due to the feature-based recording approach. Upon selecting an object, its maintenance records can be directly accessed in the interface through an intuitive interaction mode.

Figures 6(c), 6(d), and 6(e) demonstrate the visualization in the AR applications when outside the room. With the introduction of feature-based AR, objects can be rendered at a feature level, enabling the retrieval of information about each rendered object. Figure 6 (c) shows the test site without AR effect. In Figure 6(d), the rendered wall appears and obstruct the view of objects within the classroom. Figure 6 (e) demonstrates the see-through mode by removing the AR effect of walls and allows for visual inspection of the room's interior without physical entry. As the scene is constructed using feature-based 3D information, the design of the rendered effect can be dynamically adjusted (e.g., transparently present the rendered object) to adapt to users' application demands. This design represents a significant breakthrough from the traditional constraint of fixed content in the user interface.

3.3 Discussion on Occlusion Scenarios

To evaluate the application of occlusion scenarios discussed in this study, two practical tests were conducted:

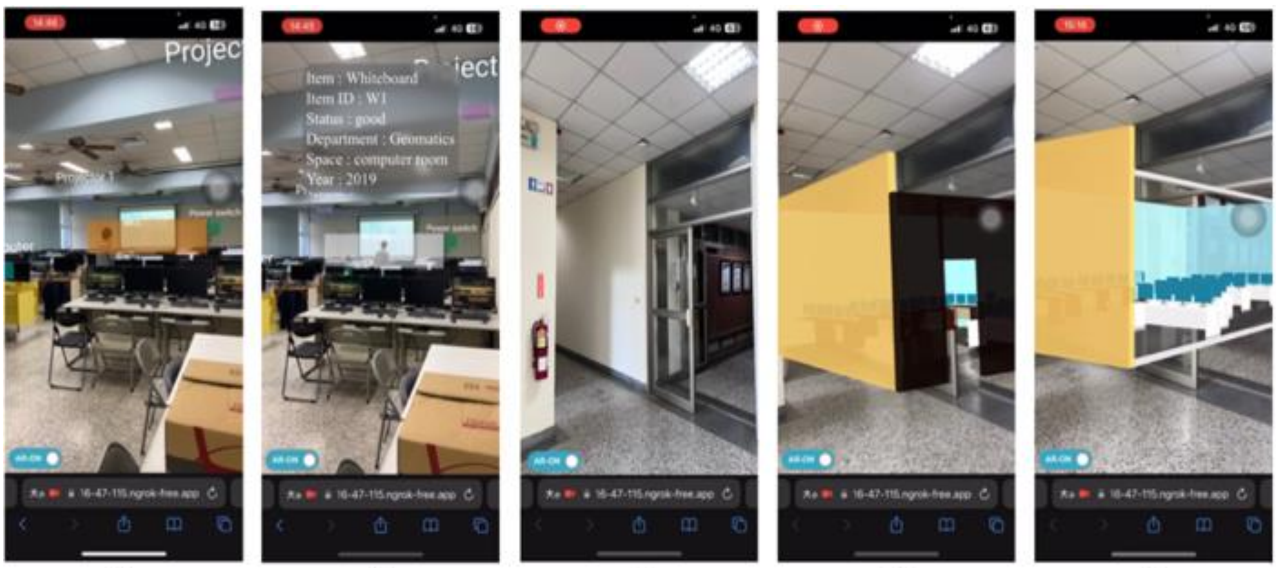
Presenting Occluded Information – Example of personnel management

By utilizing feature-based AR, it is possible to remove occluding elements, thereby leaving only the frame and creating a visually see-through effect of the interior space. In the upcoming test, we aim to observe the movement of objects within the testing environment while remaining outside the room. By attaching UWB positioning tags to an object, the system dynamically updates its position and renders its appearance in the AR-based interface.

As shown in Figure 7(a), the test only renders two point objects without other effect, making it difficult to discern their position with respect to the room. By rendering both objects and the walls of the room, it is easy to determine the two objects are inside the room with the occlusion effect (Figure 7 (b)). After selecting and removing the effect of walls, the see-through model allows users to visually inspect the interior of the room and how the two object move (Figure 7 (c), (d)). Should users have interest on any rendered object, he or she can click the rendered object and retrieve the information stored in the database (Figure 7 (e)). Based on the results, feature-based AR can not only provide abundant information from a database but also provide flexible contents with the choice of occlusion.

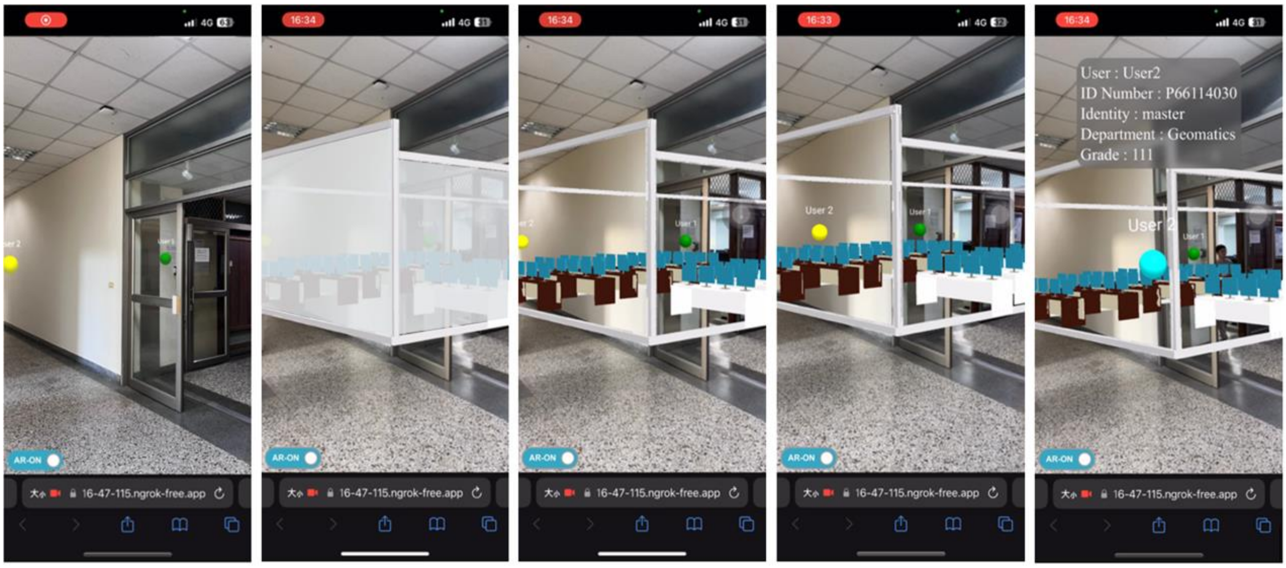
Displaying the Effect of Object Occlusion - Example of finding hidden object

Feature-based AR is capable of rendering objects in the scene based on their position to create a realistic occlusion effect. In this test, we have developed a scenario to locate hidden objects. During the display of object positions and



(a) (b) (c) (d) (e)

Figure 6. Feature-based AR Scenario: visualize objects and remove object

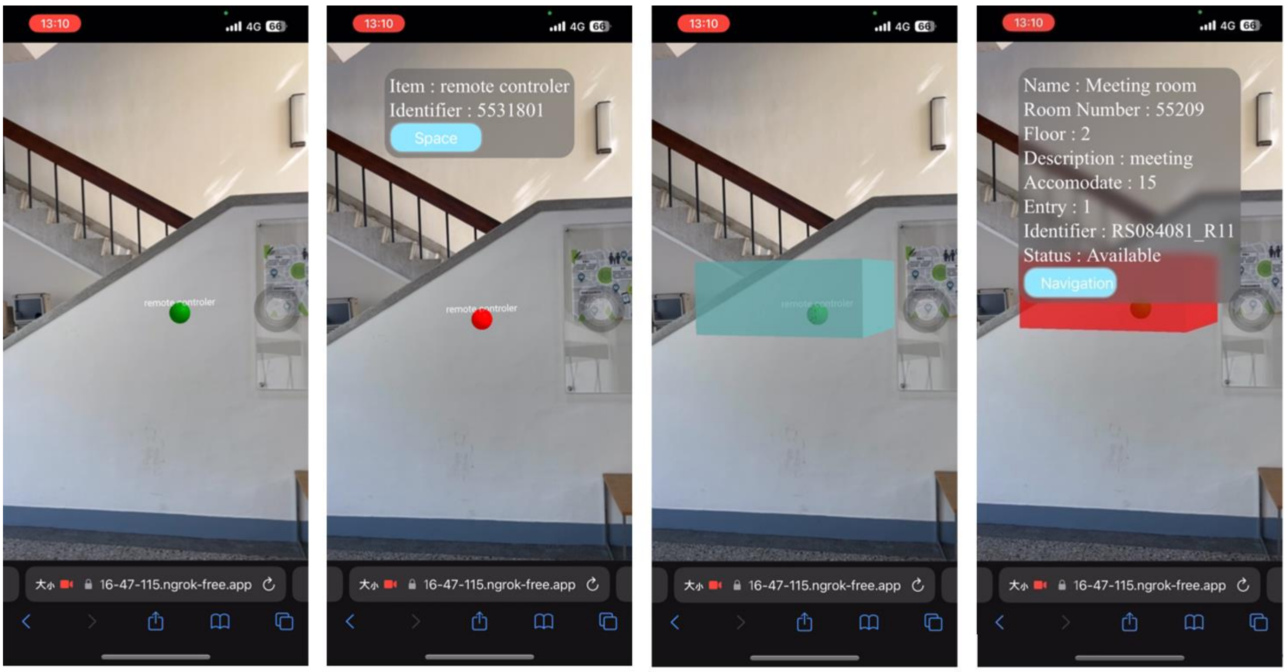


(a) (b) (c) (d) (e)

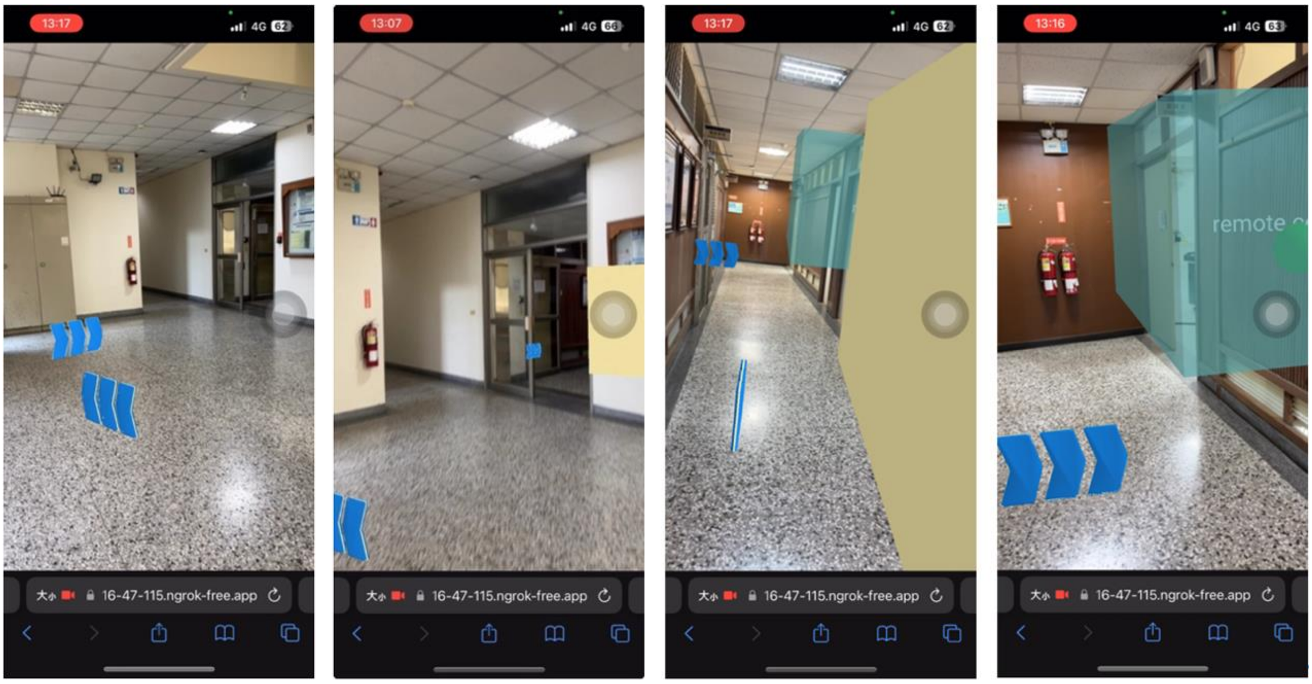
Figure 7. Presenting Occluded Information for interior moving objects

path guidance, obstacles are included to create realistic occlusion effects.

As shown in Figure 8, the illustration demonstrates how the AR interface guides the user to find a hidden object. In Figure 8(a), the green object point indicates the object is located in that direction. After clicking, the point turns red and its information stored in the database is returned. Additionally, Figure 8 (c) demonstrates more information about where the item is (within a particular room) can be further retrieved. Figure 8 (d) displays information about the room, along with the option to initiate navigation by clicking the box. Figures 8 (e)-(h) illustrate the navigation process that guides users to the specific space after clicking the Navigation button in Figure 8 (d). It involves rendering arrow icons that shows the path to the specific room (Figure 8 (e)). Occlusion effect are considered during users' movement (Figure 8 (f), (g)). This approach enables users to comprehend the relative positions of the space where the object is located with direct and intuitive visual instruction. Finally, users reach the room where the item is and can locate the items even if it is not directly viewable (Figure 8 (h)).



(a) (b) (c) (d)



(e) (f) (g) (h)

Figure 8. Effect of Object Occlusion: find hidden objects.

4 Conclusion

Due to the development of hardware and advancements in software technology, AR has become increasingly popular and ubiquitous in daily life. The application of AR is influenced by various technologies, which affect both the depth and breadth of its usage. The integration of augmented reality with GIS has become a popular research topic in recent years. This research delves deeper into the combination of these two technologies, proposing a fundamental operational framework for their integration. Essential elements for integrating these two technologies and the interactions between these elements are identified. These principles serve as a basis for the subsequent development of applications that integrate both AR and GIS. Additionally, the study introduces a design for AR scenes based on feature objectification. It incorporates rich information provided by GIS, including recorded geometric shapes, spatial relationships, and attribute data. This information serves as the primary source for creating AR scenes, improving the spatial understanding of the scenes. The design not only intuitively presents geographic information but also enhances the interconnectedness of information. Moreover, it addresses occlusion issues, making applications more realistic and visually appealing. Finally, the research implements indoor scenes based on the proposed framework to test the effectiveness of feature-based scenes in achieving various application purposes. The results serve as a reference for future applications.

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