Research on the Production of an Integrated Air-Ground Panoramic Roaming System: A Case Study of Beijing University of Civil Engineering and Architecture

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Abstract: With the advancement of image processing technology, buildings, streets, and other scenes can now be displayed in 3D panoramas. This study employs 3D panoramic roaming technology, based on the spherical panoramic image stitching method, to achieve integrated air-ground panoramic roaming for the Daxing Campus of Beijing University of Civil Engineering and Architecture. The process of data preprocessing and panoramic roaming production is meticulously documented. The specific functionalities realized in this study include the interaction between aerial and ground scenes, seamless roaming of the campus ground scenes, linkage between panoramic roaming and the navigation map, synchronization of the navigation map to display site points and radar sector positions, and the integration of the roaming system into the server.
Keywords: Air-Ground Integration; Panoramic Roaming; Map Linkage; Hotspot Jumping.

1 Introduction

Virtual Reality (VR) [1], which can be traced back to the 1960s when Ivan Sutherland developed the first head-mounted display, has rapidly evolved in recent years. VR technology has been progressively applied to various fields, including education, retail, transportation, healthcare, and sports, demonstrating vast potential for diverse applications. As the adoption of VR technology in industry grows, researchers are increasingly exploring its roles in corporate education and training, marketing, team building, and beyond.

Realizing immersive experiences for certain real-world scenes can be both difficult and costly. The application of virtual reality significantly addresses this challenge. Three-dimensional panoramic roaming is a crucial component of virtual reality technology [2]. Utilizing this technology allows users to enjoy an immersive experience remotely. To achieve this experience, images of the target environment must first be obtained. However, capturing panoramic photos directly is challenging, leading to the development of various panoramic stitching algorithms [3]. Once the panoramic image is acquired, it can be used to create a 3D panoramic roaming experience. For instance, Kelly Cao developed a virtual museum panoramic roaming system for the Hubei Museum using Pano2VR [4], Guangchao Zhang implemented a campus virtual roaming system using Vega Prime [5], and Razia Sulthana created a virtual roaming game to showcase SRM University [6].

Current 3D panoramic roaming technology often lacks interaction between sky and ground scenes, resulting in limited perspective switching and thereby hindering a comprehensive understanding of the environment. Typically, 3D campus panoramic roaming focuses on ground-level views, as shown in Fig. 1, allowing users to roam only on the ground without the ability to view or jump to ground scenes from a sky perspective. In some instances, users may need to observe the ground from above to better grasp the layout and structure of the scene. The absence of a sky scene restricts this viewpoint, thus limiting the user's overall understanding of the environment. Furthermore, the lack of a sky scene can present navigational challenges. Users may rely on landmarks or reference points visible from an overhead view to determine their desired ground locations. Without a sky perspective, these navigational aids are absent, making it easier for users to become disoriented during panoramic roaming.

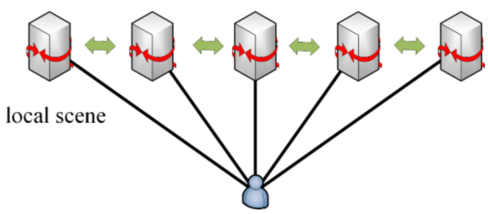


Figure 1. Schematic diagram of a panoramic roaming system that only supports local scene switching

In this study, we developed an air-ground panoramic roaming system using Krpano, as shown in Fig. 2. This system enables interaction between sky and ground scenes through hotspot jumping. Users can control the browsing direction and explore the scene in 360 degrees. In the sky scene, users can look down on the entire campus and jump to ground attractions and road nodes by clicking on hotspots, thus obtaining both an overall view and the ability to freely switch between scene details. In the ground scene, users can click hotspot buttons to move forward in the indicated direction and view their position and orientation on the navigation map. When facing a building of interest, users can click on the building name to see its introduction. By integrating sky and ground scenes, the air-ground panoramic roaming system provides a more comprehensive and diversified observation experience. Users can look down from a sky perspective to observe surrounding geographical features and landscapes, better understanding the overall layout and structure of the scene. They can freely switch between ground and sky views to explore different angles and perspectives based on their needs and interests.

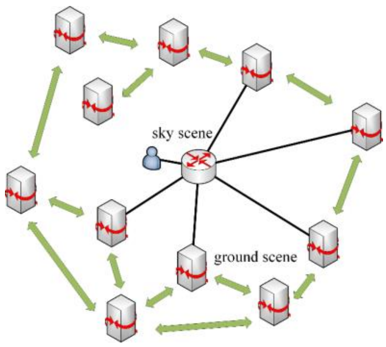


Figure 2. Schematic diagram of the air-ground integrated panoramic roaming system

Next, Chapter 2 of this paper outlines the background of the study. Chapter 3 details the design of the air-ground system, while Chapter 4 focuses on the system's implementation. Chapter 5 presents the validation of the system's effectiveness and evaluates the user experience. Finally, Chapter 6 provides the conclusion.

2 Related Work

2.1 Virtual Campus Research Progress

Today, the digital campus of colleges and universities is a key research topic for higher education researchers worldwide [7]. Virtual reality technology originated in the United States, and the level of VR research there represents the international forefront of this field [8]. Currently, VR technology is widely applied in education in the United States, with many renowned institutions such as the University of Cincinnati and Stanford University having constructed virtual campuses [9]. Similarly, many domestic institutions have developed virtual campuses; for example, Zhejiang Normal University's panoramic roaming system uses JAVA APPLET technology to achieve scene linking and switching [10]. East China Normal University developed a 3D panoramic campus roaming system based on Krpano technology [11]. However, most virtual campus browsing methods primarily involve switching between local scenes, lacking interaction between overall and local scenes. This limitation inspired the design of a sky scene for campus-wide browsing, enabling users to select and jump to specific ground scenes of interest from the sky view.

2.2 Application Tasks, Scope, and Issues Addressed by the Krpano Authoring Tool

Krpano is written based on XML, known for its good extensibility, which makes it ideal for configuring personalized and customized functions for panorama scenes in external systems [12]. Its primary applications include creating panoramic roaming experiences and embedded displays, which are widely utilized in various domains such as geography, education, and gaming. Krpano offers a rich set of interactive features that enable the creation of highly interactive panoramic images, including navigation, hotspots, and more. Additionally, Krpano provides extensive embedded display capabilities, allowing its panoramic roaming systems to be seamlessly integrated into websites for broader display and dissemination.

2.3 Comparison of Panoramic Projection Methods

Although cylindrical panoramic projection is relatively simple to shoot and stitch, it is limited by the absence of upper and lower planar scenes, resulting in a restricted field of view. Cubic panoramic projection, while easier to model, tends to suffer from deformation issues at the seams during camera rotation. In contrast, spherical panoramic projection offers an omni-directional viewing experience and avoids seam deformation problems. Therefore, this study selects spherical panoramic projection as the panoramic projection method for the system.

3 Air-Ground System Design

3.1 Spherical Panoramic Image Stitching Method

Multi-lens panoramic cameras cannot avoid the appearance of stitching seams after projecting the image onto the sphere due to the non-concentricity of each camera's photographic center. However, the points on the projection sphere are accurate and seamless. Therefore, this study generates sequential panoramic images by using splicing spheres of different radii for points at various distances, ensuring accuracy and seamless integration.

3.1.1 Spherical Projection Algorithm

Multiple cameras can be calibrated to obtain the pose of each camera. By averaging the photographic centers of all cameras, the center O of the projection sphere is determined. This center is calculated based on the average position of the photographic centers of multiple cameras, as shown in equation (1):

$$O = \frac{\sum O_i}{n} \tag{1}$$

The radius is determined based on the distance from the point to point O. Each pixel is then projected onto the sphere as both a pixel point and a projection point. The projection schematic is illustrated in Fig. 3.

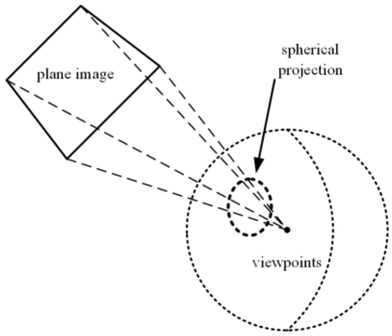


Figure 3. Schematic of spherical projection

3.1.2 Projection Sphere Parameters

The parameters of the projection sphere include its radius and pose. The radius r is defined as $r = r_0$, where r_0 is a constant. The pose of the sphere is centered at $O(x_0, y_0, z_0)$, which is calculated as the average position of the centers of multiple cameras:

$$O(x_0, y_0, z_0) = \frac{\sum O_i(x_i, y_i, z_i)}{n} \tag{2}$$

Additionally, the rotation matrix R is set to the identity matrix I.

3.1.3 Image Parameters

The pose of the image img_i is represented by the transformation matrix T_i, which is given by:

$$T_i = \begin{pmatrix} R_i & t_i \\ 0^T & 1 \end{pmatrix} \tag{3}$$

3.1.4 Pixel Point Spherical Coordinate Calculation

The image coordinate system is illustrated in Figure 4 and is configured such that each point on the image corresponds to a point in spherical coordinates.

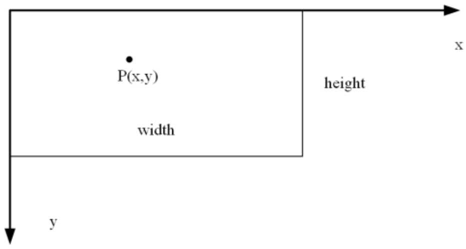


Figure 4. Image Coordinate System

The coordinates in the spherical coordinate system include the zenith angle and the azimuth angle, which are represented by the relation shown in equation (4).

$$\begin{cases} \theta = \dfrac{y}{r} \\ \varphi = 2\pi - \dfrac{x}{r} \end{cases} \tag{4}$$

The coordinates in the Cartesian world coordinate system are expressed as shown in equation (5), where they represent the coordinates on the sphere.

$$Q = \left(r \begin{pmatrix} \sin\theta\cos\varphi \\ \sin\theta\sin\varphi \\ \cos\theta \end{pmatrix} + O \right) \tag{5}$$

3.3 Sky Scene Design

By browsing the sky scene, users can gain a more comprehensive and three-dimensional understanding of the campus. Combined with the navigation map and sector radar, this system allows users to jump to specific ground scenes in a targeted manner. The functions of the sky scene include the deployment of hotspots for key ground scenes, a navigation map, and radar. Hotspots are placed to allow users to jump to corresponding ground scenes, such as the start and end locations of roads, road nodes, campus attractions, and more. The navigation map and radar display the user's relative position in the sky and their orientation, enhancing the user's navigational experience.

3.4 Ground Scene Design

The functions of the ground scene include hotspot coverage of the entire campus road network, a navigation map and radar, and the addition of scene objects. Hotspot coverage requires setting up forward and backward hotspots on all campus roads, with different configurations for campus attractions, straight roads, and intersections. The navigation map and radar display the user's position and orientation. Scene objects are used to introduce buildings and other significant features.

4 Air-Ground Integrated System Realization

4.1 Image Acquisition and Processing

There are various methods for shooting panoramic images, including using lenses with a large field of view or ordinary cameras. Large field of view lenses can quickly complete the shooting process, but due to significant image deformation, panoramic images generated from these lenses require correction and transformation. In contrast, using an ordinary camera is more time-consuming and often involves human-computer interaction or automatic methods for image stitching.

In this study, a PHIIMAX 3D panoramic camera was used to capture images, as shown in Figure 5. The camera is equipped with six F2.2 fisheye lenses, an ISO range of 100-6400, and can produce photos in 12k/8k resolution. To create the panoramic images, this study utilized PTGui stitching software. PTGui automatically identifies feature points in the photographs and aligns them to complete the panoramic image stitching. Additionally, for photos taken with fisheye or wide-angle lenses, PTGui performs lens distortion correction to ensure that the stitched images are realistic and natural.

Figure 5. PHIIMAX 3D Panoramic Camera

4.2 Realization of the Sky Scene

The implementation page of the sky scene in the air-ground integrated panoramic roaming system is shown in Figure 6. In this page, blue hotspots are laid out for jumping to key scenes on campus, such as corresponding road node locations and each college building. Users can see on the left navigation map that they are positioned directly above the center of the campus. The navigation map on the left shows the user's location at the center of the campus, along with a 360-degree view of the sky scene. The fan-shaped radar and the user's line of sight maintain synchronization with the user's orientation. When the user clicks on a ground hotspot, they are taken to the ground scene. While in the ground scene, users can click on the green hotspots corresponding to the sky scene on the navigation map to return to the sky scene.

Figure 6. Campus Roaming System Implementation Page

4.3 Full Coverage of Ground Road Hotspots in the Panoramic Roaming System

Since the roaming generated by Krpano's own MAKE VTOUR Droplet.exe is a single independent scene, it is necessary to connect all scenes through hotspot jumping to enable continuous roaming on the campus roads. Hotspots are used to add forward and backward navigation options for each scene, creating a complete and continuous roaming experience. The distribution of hotspots in the ground part of this air-ground integrated panoramic roaming system is shown in Figure 7, with each red marking point representing a hotspot.

Figure 7. Distribution of Ground Hotspots

In the experimental production of the specific ground part, there are three types of scene processing: intersections, straight roads, and campus attraction scenes. For campus attractions or building scenes, hotspots that can jump to the attraction are placed on the surrounding roads, and hotspots that can jump to nearby road scenes are placed within the scene to maintain the coherence of the panoramic roaming. At intersections, it is necessary to manually add scene-jumping hotspots for each road direction, allowing users to jump to the corresponding road scene. On straight roads, a hotspot needs to be added at the front and back of each scene, enabling users to move forward or backward along the road. Due to the large number of panoramic photos taken on each road, code is used to batch process the linear road scenes [13]. Hotspots are added at the front and back of each linear road scene, linking to their respective preceding and succeeding scenes. In this study, the keyword insertion method is used to write Python code that inserts the hotspot code into the specified scene's code block. The insertion position is shown in Figure 8, and the format of the hotspot code to be inserted for the straight road scene is shown in Figure 9.

```
<scene name="scene_01" title="01" onstart="activatespot(90)" thumburl="panos/01.tiles/thumb.jpg" lat="" lng="" alt="" heading="">

    <control bouncinglimits="calc:image.cube ? true : false" />

    <view hlookat="0.0" vlookat="0.0" fovtype="MFOV" fov="120" maxpixelzoom="2.0" fovmin="70" fovmax="140" limitview="auto" />

    <preview url="panos/01.tiles/preview.jpg" />

    <image>
        <cube url="panos/01.tiles/%s/l%l/%v/l%l_%s_%v_%h.jpg" multires="512,1024,2048,3840" />
    </image>

    <hotspot name="spot1" style="skin_hotspotstyle" ath="-180.0" atv="15.0" linkedscene="scene_00" linkedscene_hoffset="0.0" use3dtransition="true" />
    <hotspot name="spot2" style="skin_hotspotstyle" ath="5.0" atv="15.0" linkedscene="scene_02" linkedscene_hoffset="0.0" use3dtransition="true" />
</scene>
```

Figure 8. Hot Spot Insertion Position

```
<hotspot name="Forward Scene Number" style="skin_hotspotstyle" ath="-180.0" atv="15.0"
linkedscene="scene_00" linkedscene_hoffset="0.0" use3dtransition="true" />
<hotspot name="Backscene number" style="skin_hotspotstyle" ath="5.0" atv="15.0"
linkedscene="scene_02" linkedscene_hoffset="0.0" use3dtransition="true" />
```

Figure 9. Hot Spot Code Format

The keyword insertion code is written by utilizing the hotspot code to be inserted and the format characteristics of the "tour.xml" file. This code traverses the scenes in a loop, detects the file encoding, and constructs two hotspot codes at the end of each scene code block in the "tour.xml" file. These new hotspots are used to jump to the previous and next scenes, enabling continuous browsing in the campus panoramic roaming. As shown in Figure 10, the two hotspots for forward and backward navigation are deployed in a ground road scene.

Road hotspot display (eastbound) Road hotspot display (westbound)

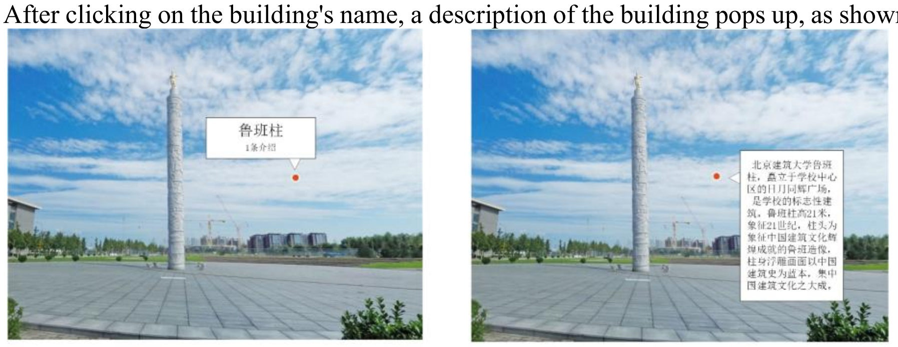
Figure 10. Road Scene Hotspot

4.4 Navigation Map and Radar

By adding a navigation map and radar, users can determine the position of the current scene within the entire roaming area and the direction they are facing. In the panoramic roaming system developed in this study, whether the user is in the sky scene or the ground scene, the navigation map displays the user's position, and the fan-shaped radar direction is synchronized with the user's line of sight. With the addition of the navigation map and radar, the panoramic roaming system gains enhanced navigation and localization capabilities, providing good roaming navigation and simple interactive operation [14].

4.5 Adding Scene Objects

When browsing a building in a scene, users may not be familiar with it. By adding polygonal objects and writing corresponding functions for mouse hover and click events, the building's name appears when the mouse hovers over it. After clicking on the building's name, a description of the building pops up, as shown in Figure 11.



Mouse over to show building name Click to show building description

Figure 11. Adding Scene Objects

4.6 Server Architecture Design

By deploying the panorama system to a server, users can access the panorama images from anywhere via the Internet, rather than being limited to local devices. Administrators can remotely manage panorama images and system settings, allowing for centralized management and updates.

To host the web pages, choose either your own physical server or a cloud service provider. Upload the web page files, including HTML files, panoramic image files, and other necessary components, to the server. Properly setting up the root directory and access rights of the website completes the deployment of the panorama system on the server. The system design is illustrated in Figure 12.

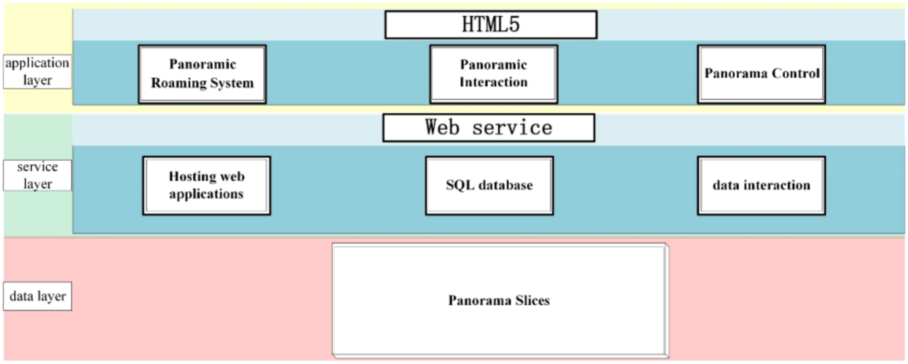


Figure 12. Panoramic Roaming System Framework Design

5 Effectiveness Verification and Experience Evaluation

5.1 Panoramic Image Quality

A road panorama was randomly selected for image clarity assessment, as shown in Figure 13. The assessment results are as follows: First, its resolution reaches 72,000,000 pixels with high pixel density, presenting rich image details. Secondly, the Laplacian variance of the image reaches 29.59, indicating high clarity of edges and details and good overall quality. In addition, the distortion level of the image is only 3.41e-05, showing that the image has no significant distortion and maintains good clarity and quality. Finally, the color accuracy is 8.68, indicating a relatively uniform color distribution and high color accuracy, which further enhances the texture of the image. In summary, this image performs well in terms of resolution, sharpness, color, and overall quality, making it suitable for use in a variety of demanding application scenarios.

Figure 13. Panoramic Image of the Road

5.2 Roaming Effect Verification

This air-ground integrated panoramic roaming system includes a total of 857 scenes, allowing seamless jumping between the sky scene and the ground scene. As shown in Figure 14, after clicking on a hotspot in the sky scene, the user can jump to the corresponding ground scene. Users can also use the arrow-shaped hotspots in the ground scene to move forward or backward, enabling continuous roaming on the campus roads.

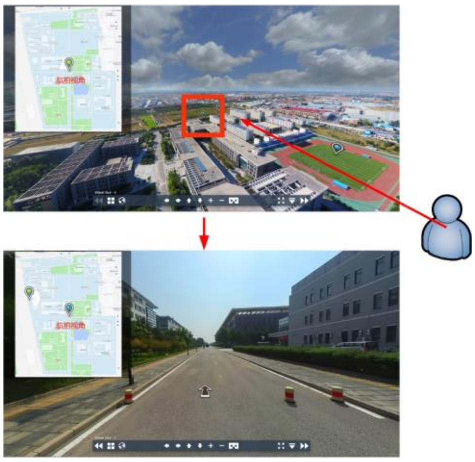


Figure 14. Jumping between Sky Scene and Ground Scene

The following are some campus attraction scenes from this air-ground integrated panoramic roaming system, including the library, playground, and more, as shown in Figure 15. In these attraction scenes, users can choose to hide the navigation map and browse the scene immersivity. They can also freely jump to nearby road scenes or return to the sky scene, enabling seamless roaming throughout the entire campus. Browsing this system helps users navigate around the campus and provides a comprehensive three-dimensional understanding of the school online.

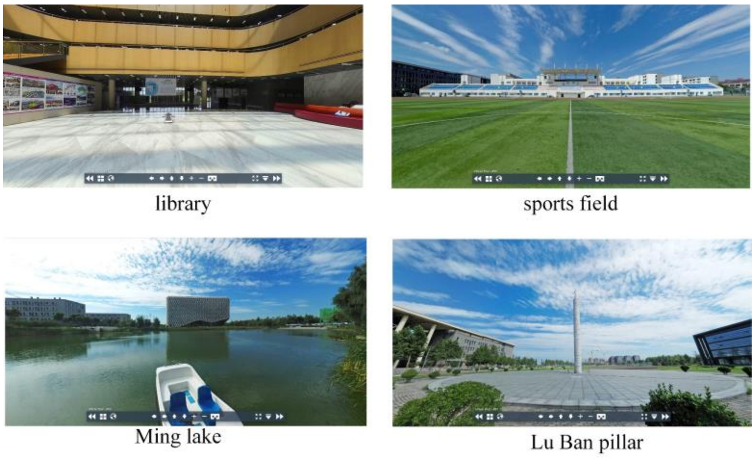


Figure 15. Campus Attractions

6 Conclusion

This paper proposes that the sky scene has significant value in the 3D panoramic roaming system and provides the design scheme and prototype implementation. In this study, Krpano was utilized to build an integrated air-ground panoramic roaming system, featuring interaction between sky and ground scenes, coherent campus roaming, and related functions. The actual running results demonstrate that the integration of sky and ground scenes achieves effective air-ground integration, enhances expressiveness, improves user experience, and provides valuable optimization suggestions and practical insights for virtual reality application technology.

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