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Workflow for Anamorphic 3D Advertising based on Image Distortion

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Abstract

In producing anamorphic 3D advertisement projects, it is necessary to apply the principles of illusion art to distort the images output to the screen (Image Distortion) so that their display aligns with our visual perception in a real three-dimensional environment. We focuse on the methods of image distortion in the creation of content for anamorphic 3D advertisement screens in this thesis. We propose using Unity 3D's real-time rendering instead of the offline rendering method of compositing method, and employing UV grid mapping to replace the manual correction in Adobe After Effects(AE). The significance of this paper lies in simplifying the image distortion processing workflow in anamorphic 3D projects and optimizing the image distortion creation methods used in compositing method. In outdoor anamorphic 3D advertisement projects, the proposed image distortion creation method demonstrates significant advantages in terms of production time, process simplification, flexibility, and expansion possibilities. Our research provides new perspectives and methods for the creation of anamorphic 3D content, offering theoretical and methodological references for professionals working on similar contents.

Keywords: *3D Production; Anamorphic 3D; Right-angle LED Screen; Image Distortion;*

1. Introduction

In recent years, outdoor anamorphic 3D advertisements have become a globally popular topic. This unique visual effect presents 3D images directly to the audience without the need for additional devices or glasses [1]. The creation of anamorphic 3D content mainly involves compositing method to produce video files that are played on two-dimensional LED screens to achieve the anamorphic 3D effect [2]. This thesis primarily investigates the production methods of outdoor anamorphic 3D advertisements.

The thesis is divided into three main sections. The second chapter details the research methods and the creation process of basic test cases. The third chapter delves into the image distortion process based on these test cases, proposing a complete workflow using UV grid mapping. The Structural Similarity Index (SSIM) comparison analysis method is employed to verify the restoration degree of images after image distortion

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processing. In the fourth chapter, a comparative analysis of the results from two different production workflows is conducted, validating that the UV grid mapping workflow proposed in this thesis significantly improves image restoration accuracy, simplifies the production process, and enhances production efficiency. In compositing method, AE' Conner Pin and Liquify tools are used for manual correction of the output video material [3]. Based on this, our study attempts to integrate the production workflow using Unity 3D and proposes the UV grid mapping method for image distortion.

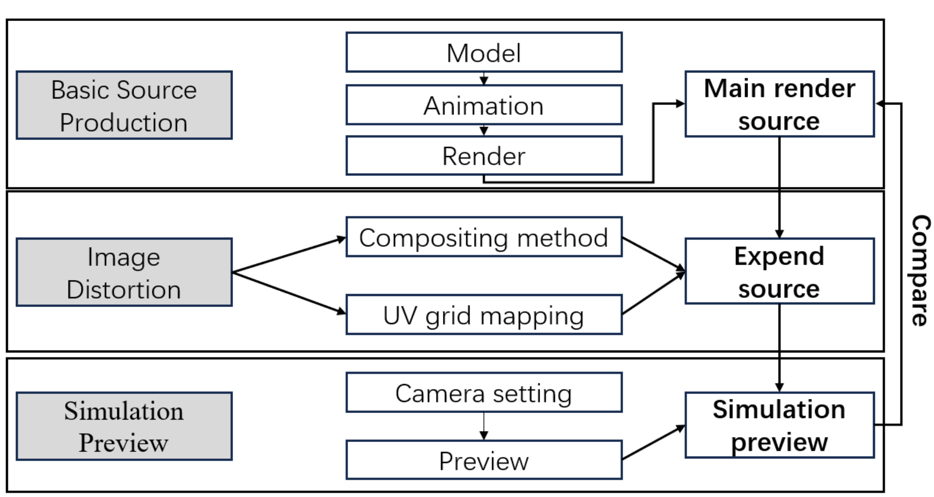
Given that current CG technology is gradually maturing, to address the issue of deployment testing, we propose simulating actual environments in a three-dimensional digital scene for deployment testing. This provides a new testing method for anamorphic 3D billboard projects [4]. Compared to real-world testing, using camera parameter settings to simulate the human eye's perspective in a virtual digital scene can achieve the same test results as in actual venues, thereby reducing the time needed for deployment testing. To obtain more accurate comparative analysis results, this thesis employs the SSIM analysis method to compare the similarity between the images output by the main rendering camera and the preview images from the simulated audience perspective. SSIM, which ranges from 0 to 1, measures the similarity between two images, with values closer to 1 indicating higher similarity. This metric was first proposed by the Laboratory for Image and Video Engineering at the University of Texas at Austin [5].

2. Experiments

2.1 Experiments Method

The entire analysis process of this study consists of three parts: the creation of basic materials, image distortion processing, and simulated audience perspective preview [6]. By comparing and analyzing the restoration degree between the simulated audience preview images and the basic materials, the feasibility of the image distortion production method is verified [7]. The images are shown in Table 1. The creation of basic materials follows the traditional CG animation production workflow, which includes CG modeling, texture mapping, character rigging, animation, and lighting rendering. Image distortion involves the basic production workflow and the UV grid mapping production workflow proposed in this paper. The simulated audience preview process serves as the validation process.

Table 1. Case production and analysis flow chart



Based on the analysis process in Table 1, three types of materials can be obtained: Main Render Source, Expend Source, and Convert Source. The Main Render Source is the output image from the main rendering camera set according to the actual needs of the project. The camera perspective can be adjusted based on the project's requirements. The output image content can be tailored to the client's needs, and the image size is adjusted according to the actual size of the LED screen on site. The images output by the main rendering camera are the final display images. The Expend Source is the image output after image distortion processing, matching the expanded size of the actual screen. Since the images captured by the main rendering camera cannot be directly displayed on the screen, they must undergo image distortion to match the perspective before they can be displayed. The Convert Source is the image obtained by simulating the real environment in a three-dimensional virtual scene for deployment testing. This image is directly obtained using the Expend Source on the simulated LED screen. The SSIM comparison test mainly analyzes the similarity between the Main Render Source and the Convert Source. The SSIM comparison analysis results are used to determine whether the Expend Source, after image distortion processing, can accurately restore the perspective relationship of the Main Render Source. This value serves as a reference for comparing the advantages and disadvantages of different image distortion methods.

The image distortion using UV grid mapping is primarily implemented in Unity 3D. In the Unity learning community, various practical plugins can be freely searched for and selected according to the needs to assist in the development of the production workflow. The code for these plugins is open-source and free, which not only helps producers quickly achieve the development goals of the production workflow but also reduces production costs [8]. To verify the effectiveness of the material deployment, it is necessary to simulate the audience perspective in a virtual scene within Unity 3D for deployment testing. The Unity Video Player plugin is used for this purpose. By setting the render mode to material override, the video material from the file can be directly read and applied as a texture onto the simulated LED screen [9].

2.2 Experiments Content Production

This case study mimics the <Food panda Pau-Pau 3D LED Billboard>, which was created by Onion Bulb [10]. The ultimate aim of this research is to validate the proposed image distortion production workflow. Therefore, the choice of the actual case for production does not have a specific purpose. The case study is solely to provide a reference for the workflow and is intended for learning purposes only.

Table 2. Basic parameter settings for case production

Title	Camera setting				LED screen	
	View of filed	Focal length	Aspect ratio	Resolution	Size	Corner subdivision
Value	55	36mm	16:9	1080P	3042*470	9

To ensure the accuracy of image distortion, it is necessary to standardize the camera parameters and image dimensions in the early stages of actual case production, as shown in Table 2. The size of the LED screen can be obtained by measuring the actual scene. Since this study does not have an actual LED screen for deployment, the image dimensions are determined based on the reference case. The animation duration is set to 12 seconds, with a frame rate of 24, and the base image dimensions are 1920*1080. The simulated LED screen dimensions are 3042*470. The corner subdivision is set to 9, which makes the rotation angle of each subdivision face 10 degrees, facilitating subsequent calculations and expansion.

During the model preparation phase, it is crucial to standardize two aspects: the LED screen size and the camera parameters. The LED screen size is set to ensure that the rendered video material can be accurately deployed onto the actual LED screen, clarifying the range of changes for the expend source. The camera parameters are set to accurately obtain the grid reference needed for image distortion, to define the aspect ratio during the image distortion process, and to ensure consistency in the viewing angle when previewing the deployment from the simulated audience perspective.

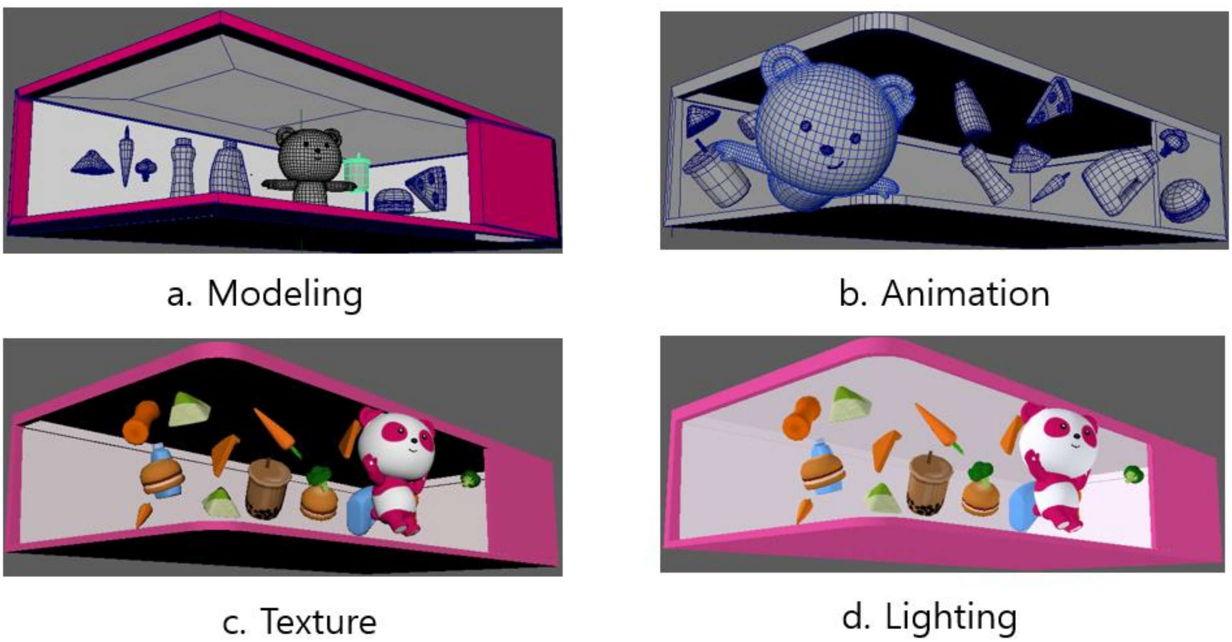


Figure 1. Basic materials creation process

The creation of basic materials includes four parts: Modeling, Animation, Texture, and Lighting, as shown in figure 1. When producing an anamorphic 3D billboard project, it is customary to have dedicated designers provide an animation script and basic model references at the project's inception. This clarifies the style of the images and the duration of the animation, which are essential prerequisites for creating basic materials. The animation production part uses a combination of skeletal rigging and manual keyframing.

All basic material creation needs to be done from the main rendering camera perspective to ensure that the perspective relationship of the final rendered images aligns with the script design. The lighting setup follows the same principle. To minimize the impact of lighting and shadows on the SSIM comparison analysis results, only one HDRI environment light is set up in the scene. The HDRI environment light is read in the form of a texture, so it can be recognized in both Unity and Maya. This type of light source is chosen primarily to reduce the impact of lighting and shadow variations on the SSIM results. For commercial projects, the light source can be freely chosen based on the needs to create richer visual effects.

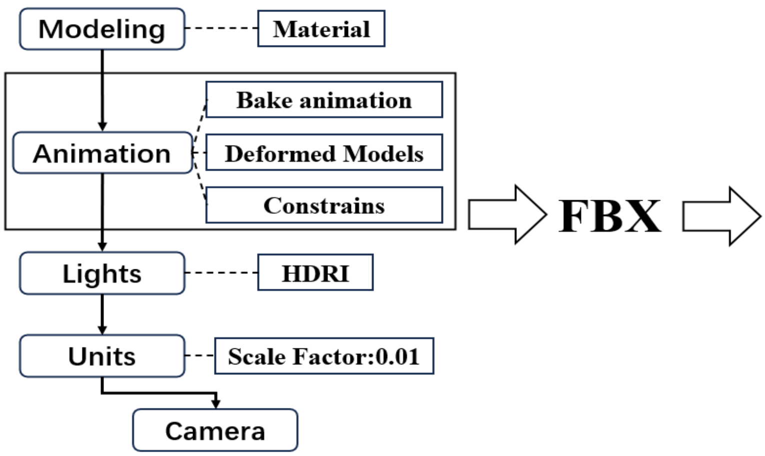


Figure 2. File conversion process from maya to unity

In Maya, the "Send to Unity" tool can be used to directly send models and animation files from the scene to the Unity 3D project folder in FBX format. The models and basic materials are fully packaged and can be directly used in Unity. This feature addresses the issue of data loss that occurs when importing and exporting files between two different software programs, simplifying the export and import process while maintaining the consistency of models, materials, and animations. Figure 2 illustrates the parameter settings during the file conversion process.

Since K-frame animation is added to the models in the scene, and the main character is also rigged with bones and controllers, it is necessary to select these animation settings during export. Due to differences in the light simulation algorithms of the two software programs, lights exported from Maya cannot be recognized in Unity. Therefore, the included HDRI file needs to be imported into Unity, and the lighting environment needs to be reset. Additionally, the default unit for world coordinates in Maya is centimeters, while in Unity, it is meters. Hence, the coordinate axis scale of the exported files needs to be adjusted to 0.01 so that the model's position and scale can be accurately restored in Unity using the convert units feature.

3. Results

3.1 Compositing Method

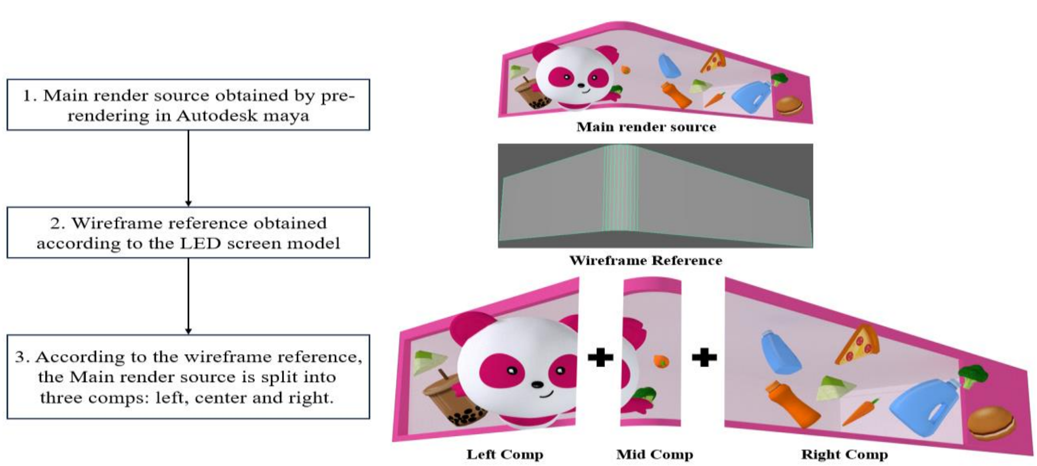


Figure 3. Main render source split description

As shown in Figure 3, the materials created in Maya are exported as sequences. These materials cannot be directly deployed onto the LED screen, so post-production compositing is required to process the images. To minimize distortion, the images are split into three parts based on the grid lines of the curved screen: Left comp, Mid comp, and Right comp. The images on the left and right sides are planar images split along the X and Y axes. When processing image distortion, only the positional information of the four vertices needs to be restored to correct the perspective relationship in the images. The middle image is a curved image generated based on a 45-degree angle between the X and Z axes. To restore the perspective relationship, a corresponding Liquify effect needs to be created separately, so it is isolated from the rest of the image. The middle image is the critical part of the image distortion process.

Currently, large outdoor advertising screens are mainly divided into two types: right-angle corners and curved corners. Right-angle corner screens only need the images to be split into two comps along the right-angle edge. Then, the Liquify tool is used to correct the stretching at the seams. This type of screen production method is relatively simple, but the principles and methods are the same as those for curved corner screens.

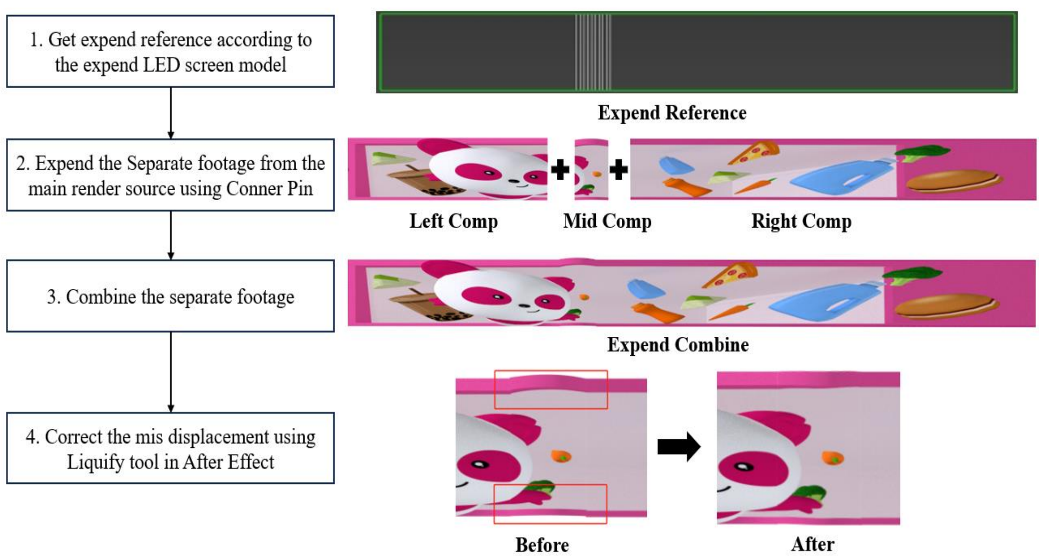


Figure 4. Manual correction of screen stretching using the liquify tool

The split Main Render Source cannot be directly deployed onto the LED screen and requires further processing. First, the curved corner planes in the LED screen model need to be sequentially rotated along the Z-axis to unfold the entire model into a complete screen. In the earlier LED screen setup, we preset the number of segments at the corner to be 9, so each plane is rotated by 10 degrees, summing up to exactly 90 degrees. When creating projects for curved screens, the corners can be set similarly, making the unfolding process more convenient and improving production efficiency.

After unfolding the LED screen model and applying UV Box, a complete expend reference is obtained. The next step is to process the previously split three images. As shown in Figure 4, when the unfolded images are stitched back together, stretching and distortion occur at the seams, failing to correctly reflect the perspective relationship at the curved corners. We use the Liquify tool to correct the stretched areas. The Liquify tool is a built-in distortion tool in AE, but this method is not the only option. Many other AE plugins can achieve the same purpose.

The basic principle of production is the same: manual adjustment by the producer to gradually restore the perspective relationship of the images, reducing local misalignment and stretching issues. This process usually requires repeated deployment testing and adjustments to the materials based on the test results until the optimal effect is achieved.

Figure 5. Expend source by compositing

As shown in Figure 5, this is the final deployment material rendered in AE after post-production adjustments. The entire material is obtained by unfolding the original Main Render Source after image distortion processing. Anamorphic 3D outdoor advertisements use the art of visual illusion to create a three-dimensional spatial effect for the audience, essentially presenting a deformed two-dimensional image in three-dimensional space.

In Unity, simulated deployment testing is conducted to check whether the unfolded images after image distortion correctly restore the perspective relationship of the original images. Therefore, at intervals of 30 frames, six key frames from frames 90 to 240 are selected for SSIM comparison analysis with the corresponding frames of the Main Render Source to detect the accuracy of image restoration.

Table 3. Compositing process SSIM compare results

Frame	Main render camera	Simulation preview	SSIM
90			0.9204
120			0.9113
150			0.9060
180			0.9008
210			0.9083
240			0.9076

The material produced using post-production compositing needs to be rendered twice in Maya and AE to ensure the accuracy of the comparison results, with the rendering precision in Maya increased accordingly. The image resolution is set to 2560x1440, the Arnold camera sample (AA) value is set to 5, and the diffuse sample parameter is set to 100. The comparison process is shown in Table 3. The analysis results indicate that the SSIM values of the six images all remain above 0.9. The SSIM value for frame 90 is the highest at 0.92, indicating the highest similarity. As the number of models in the images gradually increases, the overall similarity tends to decrease. At frame 108, when the main character occupies the entire curved corner position, the similarity reaches its lowest value of 0.9008. This indicates that the stretching issue at the curved corner is relatively noticeable at this point.

3.2 UV Grid Mapping Method

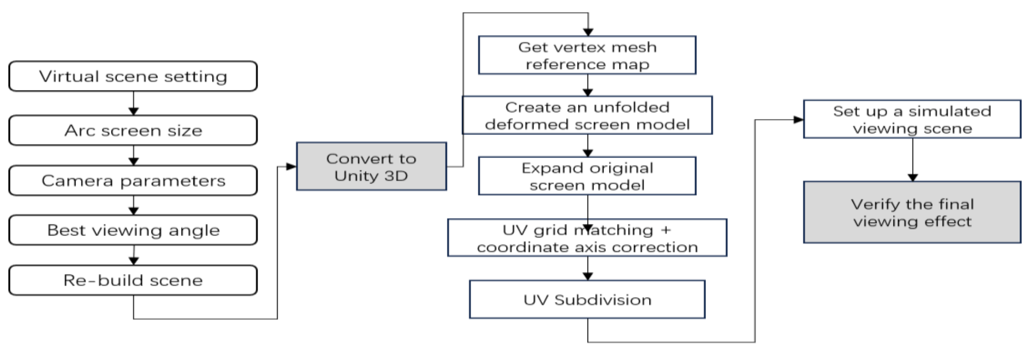


Figure 6. UV grid mapping transformation workflow

The UV grid mapping method simplifies the image distortion process, as shown in figure 6. In the initial basic model creation phase, Autodesk Maya is primarily used for animation production. After completing the animation, the project files can be directly exported in FBX format and then opened and used in Unity 3D. During the scene file conversion process, the included lighting, material, and animation information can be fully presented in Unity 3D. The image distortion process advocated in this thesis primarily utilizes Unity's real-time rendering and texture transmission functions. Therefore, steps such as obtaining grid reference maps and UV subdivisions are all completed in Unity. Finally, the production effect is verified by simulating the deployment method in real-life scenarios within Unity.

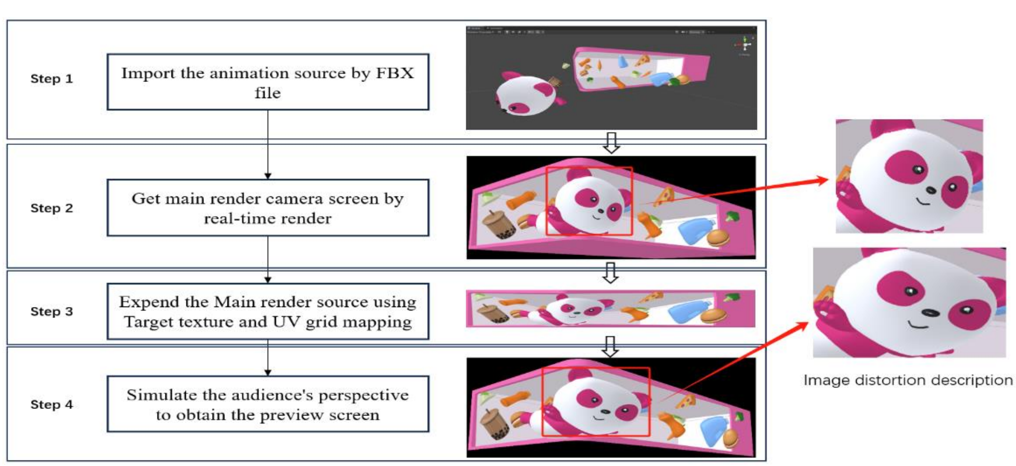


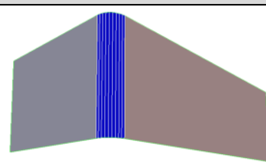
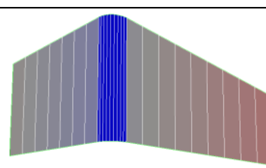
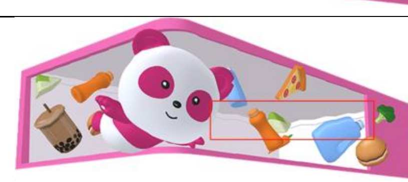
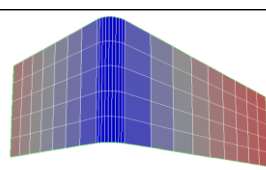
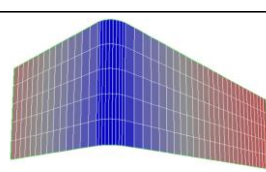
Figure 7. Image distortion by UV grid mapping

First, import the animation files from Maya into Unity in FBX format, and set the corresponding lighting and material parameters. To unify the camera position information and parameter settings, save the virtual camera in Maya as a separate file and import it into Unity, replacing Unity's original main camera. This allows obtaining the same Main Render Source from the perspective of the imported camera as in the Maya scene, as shown in Figure 7.

Using the Target Texture tool, transfer the image captured by the main camera to the unfolded screen model to directly obtain the video material for deployment output. Then, by setting up a virtual camera and LED screen from the simulated audience perspective, preview test images can be obtained. With Unity's real-time rendering capability, these image transfers are conducted in real-time synchronization.

Analyzing the preview images obtained from the simulated audience perspective, it is found that although the UV grid mapping method solves the seam and image stretching issues at the curved corners of the screen, the distortion on both sides becomes more severe. As shown in the image distortion description in Figure 4, the unfolded image exhibits significant stretching along the X-axis direction.

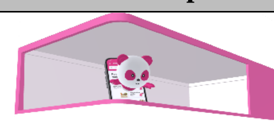
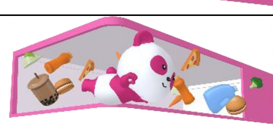
Table 4. Image distortion optimization by UV subdivision

UV subdivision	Expend UV area distortion	Convert source
Basic		
6*8		
4*6*8		
4*12*24		

To address the image stretching along the X-axis direction, it is necessary to optimize the subdivision of the UVs on the unfolded screen model. Area distortion can be used to check if the local shapes are distorted or stretched when UV coordinates are mapped onto the 3D model surface. By analyzing the area distortion range of the UVs, it is evident that the blue areas are concentrated in the curved corner section in the middle of the screen, while the images on both sides are of uniform color. This indicates that the UVs on both sides did not correctly reflect the mapping effect when projected onto the model. We can increase the number of UV subdivisions to correct this issue.

As shown in Table 4, in the first test, six subdivisions were added to the left side of the image along the X-axis direction, and eight subdivisions were added to the right side. At this point, the stretching issue along the X-axis direction was significantly improved, but different degrees of wavy deformation appeared along the Y-axis direction. After adding four subdivisions along the Y-axis direction, the wavy deformation disappeared. To further verify the impact of UV subdivisions on the image distortion effect, additional tests were conducted with 4*12*24 subdivisions, but the overall improvement was not significant. The color distribution pattern in the area distortion also indicated that increasing the subdivision value did not cause noticeable changes. The results show that the number of UV subdivisions can directly affect the image distortion effect: the higher the subdivision, the better the distortion effect. However, once the number of subdivisions reaches a certain level, the improvement effect gradually diminishes.

Table 5. UV grid mapping method SSIM compare results

Frame	Main render camera	Simulation preview	SSIM
90			0.9725
120			0.9683
150			0.9578
180			0.9553
210			0.9602
240			0.9589

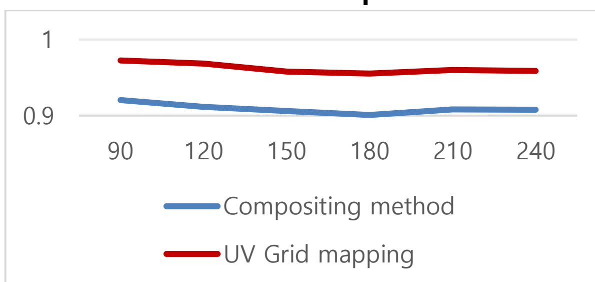
To standardize the analysis, all rendered materials are set with the same lighting environment and material settings, and the image resolution is 2560x1440, as shown in Table 3. By analyzing the table, it can be found that using the UV grid mapping method for image distortion keeps the overall SSIM values above 0.95. At frame 90, at the beginning of the animation, the similarity is 0.97, just 0.03 away from being completely identical, indicating that there is almost no image stretching issue at this point. Similarly, as objects increase in the image, the SSIM values show a downward trend from frames 120 to 180, with the lowest value of 0.9553 occurring at frame 180, as shown in Table 5.

4. Discussion

Through the production of an example case, image distortion was created using two methods:

post-production compositing and UV grid mapping. The image captured by the main rendering camera is defined as the main render source. The unfolded image after image distortion processing is defined as the expend source. The image obtained through simulated real-world deployment testing in Unity 3D is defined as the convert source. The SSIM analysis method is used to compare and analyze the similarity between the main render source and the convert source to verify the superiority of the production methods proposed in this thesis.

Table 6. SSIM compare result



As shown in Table 6, the blue line represents the SSIM value variation curve using the post-production compositing method, while the red line represents the SSIM value variation curve using the UV grid mapping method. The values of the blue line fluctuate between 0.9 and 0.92, while the values of the red line fluctuate between 0.95 and 0.97. The overall trend of both curves remains consistent, with the highest values occurring at the initial 90 frames when the number of objects in the image is minimal. Based on this, it can be concluded that both production methods can restore the perspective relationship in the main render source with a similarity of 90%. The image distortion produced using UV grid mapping has an overall image restoration accuracy that is five percentage points higher than that of the post-production compositing method. Therefore, the image distortion method using Unity 3D proposed in this study shows an overall improvement in image restoration accuracy compared to the post-production compositing method.

Table 7. Rendering time comparative analysis

Frame Render		Maya Anrold	Unity 3D
Camera Focal Length		36mm	
Lighting		aiSkyDomeLight (HDRI)	Skybox (HDRI)
Material		Basic	Basic
Render Time	720P	6s	Within 1s
	1080P	14s	Within 1s
	2K	51s	2s
	4K	3m31s	6s
	Full（1080P）	3h19m46s	5m42s

Secondly, to validate the improvement in production efficiency proposed in this thesis, the rendering times of the two production workflows were compared. Under the same camera focal length, lighting environment, and material settings, single-frame images of 720P, 1080P, 2K, and 4K resolutions, as well as a complete 1080P animation, were rendered separately. As shown in Table 7, all materials were rendered on the same computer configuration, making the comparison of rendering times between the two software programs valuable. Using Unity 3D significantly reduced the rendering time. Particularly for the complete video material, the rendering time was shortened by more than three hours at the same quality. Moreover, after rendering all the materials in Maya, they cannot be directly used as the final deployment material; further image distortion processing is required in AE, necessitating a second round of rendering and additional rendering time.

Table 8. Production workflow comparative analysis table

Title	Compositing method	UV grid mapping
Model	●	●
Animation	●	●
Light	●	●
Render	●	
Wireframe reference	●	●
Expend reference	●	
UV reference		●
Split	●	
Expend	●	
Re-combine	●	
Re-render	●	
Expend source	●	●

As shown in Table 8, both image distortion production methods require the creation of basic materials in the preliminary stage. Using the post-production compositing method for image distortion involves splitting the image along the X-axis based on the LED screen model's wireframe, then recombining and manually adjusting to correct perspective relationships and seam issues.

The UV grid mapping distortion method primarily uses adjustments of UV Y-axis and Z-axis weights to correct the perspective relationship of the image. Unlike the post-production method, the X-axis and Y-axis adjustments here are based on the entire image rather than splitting it into individual parts, thus avoiding seam issues that arise after splitting. Additionally, using Unity 3D's Target Texture feature allows the main render source captured by the rendering camera to be transferred in real-time to the expend screen model, avoiding the repeated rendering output process. With Unity's real-time rendering capability, all image transfers occur in real-time synchronization. Therefore, any modifications to each image can be immediately reflected in the pre-set preview images, simplifying the iterative rendering process of video material adjustments in the post-production method.

Based on the case production and comparative analysis results, the UV grid mapping method proposed in this thesis can achieve over 95% restoration accuracy for anamorphic 3D advertisement projects, compared to the 90% restoration accuracy of the post-production method, improving the image distortion effect. Furthermore, the production process is simplified by eliminating the need for splitting images, recombination, manual perspective correction, and repeated rendering. Unity's real-time rendering feature also significantly reduces rendering time. The UV grid mapping method proposed in this study demonstrates superior performance in production workflow, work efficiency, and final effect compared to the post-production method.

5. Conclusion

In this thesis, we proposed the UV grid mapping method, is an image distortion production method implemented in Unity for creating anamorphic 3D billboard content. This method leverages Unity's real-time rendering capabilities to achieve image distortion, replacing the offline rendering used in the post-production compositing method. Consequently, this production workflow benefits from the flexibility afforded by real-time rendering.

The post-production compositing method involves rendering videos of specific specifications in animation production software, which has a long production and modification cycle. Post-production debugging and calibration are cumbersome, requiring re-rendering for every modification, which demands significant time and effort. Since the display content is a video file, the optimal viewing angle is fixed during video production and cannot be adjusted later. Each project's screen size differs, so custom video production is necessary to avoid content stretching. Such content cannot be reused on other project screens without causing stretching, distortion, and reduced clarity.

Using Unity 3D for image distortion allows for real-time visibility of the final display effect. Modifications and position adjustments can be made in real-time, with content being confirmed and saved instantly, making the process simple and fast. Unity 3D's real-time content output supports unlimited resolution and any aspect ratio, achieving point-to-point optimal clarity and the best display effect for screen content. Since the display content is output through three-dimensional real-time rendering, the optimal viewing angle can be adjusted according to the usage scenario, meeting the viewing needs for different scenarios.

Because the system uses three-dimensional real-time rendering technology for display content output, the screen size only affects the amount of content visible to the audience. Thus, a single set of anamorphic 3D content can be used on different screens across various projects without any modifications. Simply adjusting the output image size ensures that the display content is correct, with no stretching or distortion.

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