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Zoom for Virtual Reality based on Moebius Transformations

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Abstract

Interest in omnidirectional images and videos has grown with the availability of 360 ° high-definition viewing devices and cameras ranging from YouTube on smartphones to the sophisticated Head Mounted Displays that are increasingly available to the public. The outstanding features in videos displayed in virtual reality, the viewer's freedom in choosing wherever to look to and the exceptional sensation of immersion offer enormous authorship possibilities for content creators, on the other hand, impose restrictions on the applications of traditional elements of the cinematographic language. Among these features, there is a debate about the applicability of zoom in VR, due to lack of quality resulting from the conventional transformations in spherical images, and to the risk of immersion breaking.

In this work we approach the zoom as an element of cinematographic language applicable in virtual reality. We describe a Moebius transformation on videos as a mathematical formulation more appropriate to operate in spheric functions and, as a consequence, resulting in a natural zoom tool for editing and visualization of omnidirectional images. In addition, we present different ways to use this zoom at run time, according to the observer's viewpoint and the parameters set by the content creator at production time.

1 Introduction

With the improvement and popularization of capturing and visualization technologies, there is an increasing relevance of understanding how the resources used in film language apply in this new reality, what resources no longer make sense and what new resources can be created.

In VR, the main pillars that characterize an experience are the opportunities for immersion, the potential for a unique experience of empathy and the control by the audience [7]. These are the three main elements that we observe as opportunities and also as constraints to the use of resources of cinema and theater in cinematic VR production.

One of the resources in debate for its application in Cinematic VR is Zoom. On one hand, there is the argument that zoom does not apply either because the camera movements must be under the viewer's domain or because the zoom in the sphere distorts the geometry of what is being observed, in both cases, interrupting the immersion. In our research, we are developing experiments that address these two aspects: zoom quality and application dynamics.

Regarding quality, we developed a zoom based on the Moebius transformations on the sphere. Because they are conformal transformations, they preserve geometric characteristics of the image in transformation so that the result seems more natural. This natural perception depends on the angle of view range, since the Moebius transformation further distorts the image the greater the distance from the transformed point to the reference center or point of view. Additionally, the head movement during the zoom application generates a perception of non-correspondence with the movement of the image, similar to movement while using a binocular. Another phenomenon to be observed is that the zoom application, if exaggerated, cuts the experience feeling of reality and the immersion.

For these reasons, we understand that limits should be studied where zooming is sufficient to provide a natural experience and at the same time provide the dramatic effect desired by the creator.

2 Related Work

The work presented in [1] describes a complete real-time system for zooming and pan interactive on high definition panoramic videos. Compared to existing systems using clipping perspective panoramas, the approach in [1] creates a cylindrical overview. In this case, the perspective is corrected in real time, and the result is a better and more natural zoom.

In [2], Peñaranda, Luiz Velho and Sacht present a technique to improve the perception of panoramic viewing quality. The main ingredients of this approach are to consider the sphere of vision as being the Riemann sphere, which makes it natural to apply Moebius transformations to the input image, and to establish a projection scheme that changes depending on the field of vision used. They also introduce an implementation of the method, compare it with images produced with other methods, and show that the transformations can be done in real time, which makes this technique attractive for existing or new interactive panoramic applications.

In [3], Schleimer and Segerman propose the Moebius transformations as a natural tools of scale and rotation to be used in the edition of spherical images. As applications, they show how to get the "Droste" and other interesting visual effects using Moebius and other conforming transformations.

In [4], Souto, Sacht and Luiz Velho present a new method to transform omnidirectional images based on a combination of Moebius transformations in the complex plane that are localized by Gaussian weights to limit the action of these mappings to regions of interest. Because no optimization or numerical method is involved, it is possible to achieve real-time performance with the method, making it applicable to streaming services. The results show the potential of this technique in areas such as security and art in general.

3 Virtual Reality and the Cinematographic Language

We call cinematographic language the set of planes, angles, camera movements, assembly features, lights, sounds, argument, frames and sequences that make up the universe of a movie. For this, it must be taken into account that each has its psychological effect, a specific dramatic value and plays its part within the totality that is a film.

Comparing media supports for traditional cinema and 360 degree cinema, we have television and film in the first case, and in the second case spherical projections on domes and devices with tracking of the observer's direction, such as Head Mounted Displays (HMD) and tablets.

In analyzing the elements of traditional cinema language in comparison to its possibilities in virtual reality, in addition to the intentional dramatic and psychological effects, we must consider the undesirable effects that can cause on the viewer during his experience.

If employed improperly, some resources may break the feeling of immersion by sending a "message" to the viewer that he is not physically present in that experience. This "awakening to reality", besides overriding the main effect of VR, the immersion, can cause problems like motion sickness.

Another key feature in VR to consider is the viewers freedom to look wherever they wish. While this freedom provides tremendous opportunities in the VR experience, at the same time it interferes with the power of the director in driving the viewer's gaze. In traditional cinematography the director determines what the viewer will watch, under which plane, angle, framing and camera movement, while in VR the director restricts himself to choosing the position in which the viewer is in relation to the scene, seeking subtlety in the visual effects not to compromise immersion.

Still under the risk of immersion breaking, the editing features are severely restricted, since each cut sends a signal to the viewer that the experience they are experiencing is not real. With this, the authors either seek to disguise the editing resources in the narrative or seek to minimize its use.

Finally, considering that camera movements form the basis of traditional cinematic language, it becomes important to analyze them in comparison with cinematic language for virtual reality.

3.1 Traditional Cinema

- **Cinematographic Camera Movements:** They constitute the technical basis of the moving plane. They are defined taking into account if the movement of the camera is a translation (moving in advance or retreat, rising or falling), a rotation (about its axis) or a change of the field of vision relative to the spectator. See Fig. 1.
  - **Travelling:** The camera is moved on a cart (or any movable stand) on a horizontal axis and parallel to the movement of the shot. This monitoring can be lateral or frontal, in the latter case it can be approach or distance.

- **Panoramic:** The camera moves around its axis, making a rotating movement, without leaving the place. This is a camera movement that can be horizontal (from left to right or from right to left), vertical (from top to bottom or vice versa) or oblique. Vertical panning is also known as tilt.
- **Zoom:** In zooming, the camera remains fixed and its lens assembly moves, causing the subject to appear farther or closer to the image.

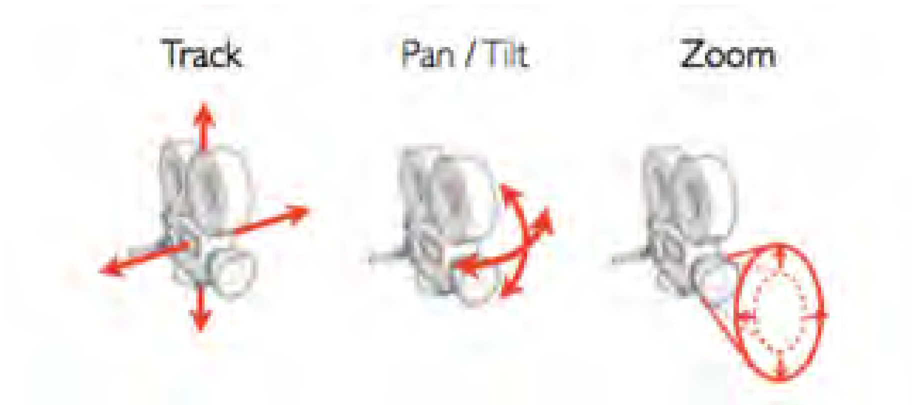


Figure 1: Camera movements in Cinema.

3.2 360 degrees Cinema

- **Omnidirectional Camera Movements:** As in VR the observer has the control of the point of view, unlike the traditional cinema, in the cinema 360 degrees the movements of the camera can be determined at the moment of the capture of the image by the director or during the visualization by the observer. See Fig. 2.
  - **Travelling:** The translation movement can be applied in recording time, in general in the dramatic situations that supposes the spectator moving, for example in a vehicle.
  - **Panoramic:** The rotation movement is carried out at visualization time by the observer's initiative or by image transformation.
  - **Zoom:** There is debate about the use of zoom in VR. First, there is the premise that omnidirectional cameras do not have the capabilities to change their field of vision, since they record a 360-degree image. However, in fact, the zoom results from the variation of the field of view in the viewed scene and the reference field of view of the viewer. Thus, it is possible to create the sensation of zooming in VR with a transformation of the image. On the other hand, there is the difficulty in developing a zoom transformation that is perceived as natural to the observer, since the projection surface is a sphere and not a plane. In addition, even with natural zoom, the camera does not stay fixed. As the viewer has the freedom to look in any direction, he may not be looking at the object of interest to zoom in.

In this work, we offer a zoom using Moebius transformation as a solution that creates a natural perception for the observer and also explore ways of zoom editing at post-production time and controls at viewing time.

4 Representations of Omnidirectional Images

Any scene observed from a fixed viewpoint at a given moment can be modeled as the unit sphere centered at the viewpoint ($\mathbb{S}^2 = \{(x, y, z) \in \mathbb{R}^3 | x^2 + y^2 + z^2 = 1\}$) on which each point has an associated color, the color that is seen when one looks toward this point. Here we assume that the viewpoint is the origin of $\mathbb{R}^3$ for convenience.

This sphere we call *viewing sphere* or *omnidirectional image*. Notice that the viewing sphere represents the whole 360 degrees longitude and 180 degrees latitude field of view.

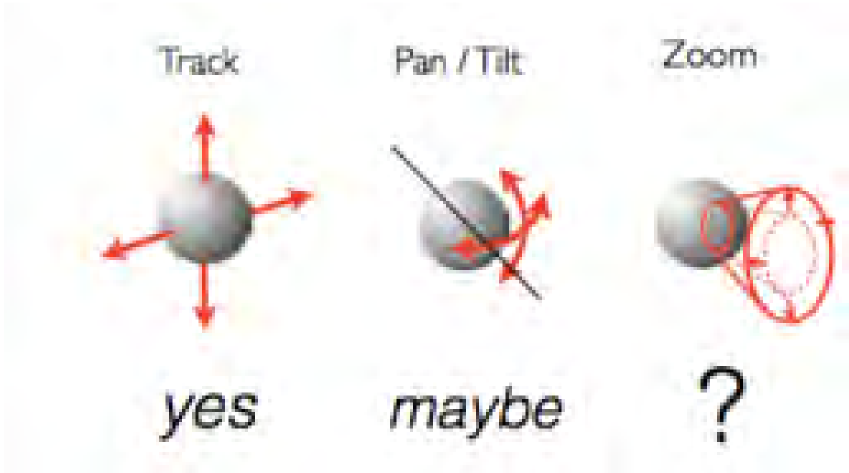


Figure 2: Camera movements in VR.

A well known and useful representation of $\mathbb{S}^2$ is the one by latitude and longitude coordinates, or *equirectangular representation.*

$$r : [-\pi, \pi] \times \left[-\frac{\pi}{2}, \frac{\pi}{2} \right] \to \mathbb{S}^2$$
$$(\lambda, \phi) \leftrightarrow (\cos\lambda\cos\phi, \sin\lambda\cos\phi, \sin\phi) \quad (1)$$

This representation is illustrated in the figure 3.

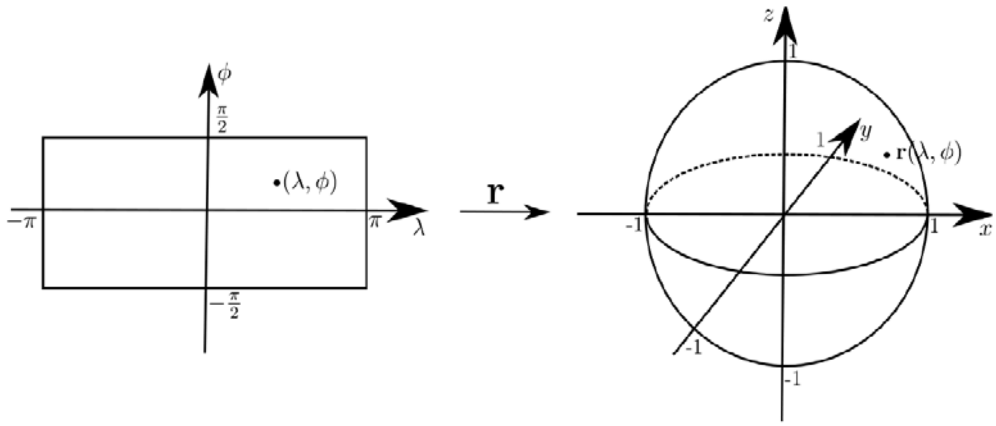


Figure 3: Latitude/Longitude representation.

It is known that the complex plane can be identified as an unitary sphere (in our case, the visible sphere) through a stereographic projection. Identifying the point from which the projection lines emanate as ∞, obtaining a continuous mapping $\mathbb{SP} : \mathbb{S}^2 \to \mathbb{C}_\infty = \mathbb{C} \cup \infty$ that have continuous inverse $\mathbb{SP}^{-1} : \mathbb{C}_\infty \to \mathbb{S}^2$. An important property from stereographic projection is your conformity, i.e., it preserves angles, orientation and maps circles in circles or lines. This way of interpreting the extended complex plane $\mathbb{C}_\infty$ as a sphere was formulated by Riemann and is called *Riemann Sphere*. In our work, we will consider the visible sphere as the Riemann Sphere with ∞ being the opposite point to the projection plane.

5 Moebius Transformations for Virtual Reality

Almost universally, spherical videos and images are stored and transmitted in the equirectangular representation: points on the sphere are given by their latitude and longitude coordinates (1) and the complete image is stored as an equirectangular image. This format is convenient for image

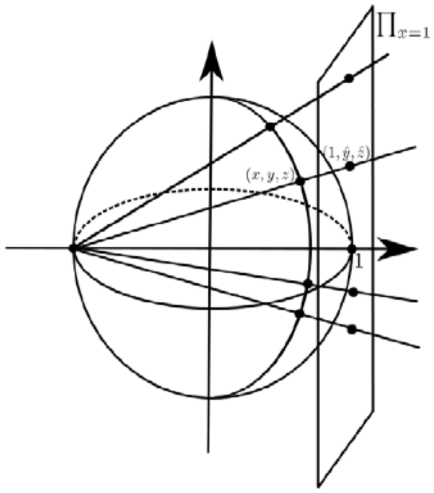


Figure 4: Stereographic Projection.

processing, but a problem appears when working with spherical images: the softwares developed for ordinary rectangular images do not recognize the equirectangular projections.

Since they are conformal, the Moebius transformations present the advantage of preserving angles and producing other interesting effects, favoring a more natural experience to the observer in a zoom or scale application.

The Moebius Transformations can be classified into three canonical forms, namely: Elliptic, Hyperbolic and Parabolic. See figure 5.

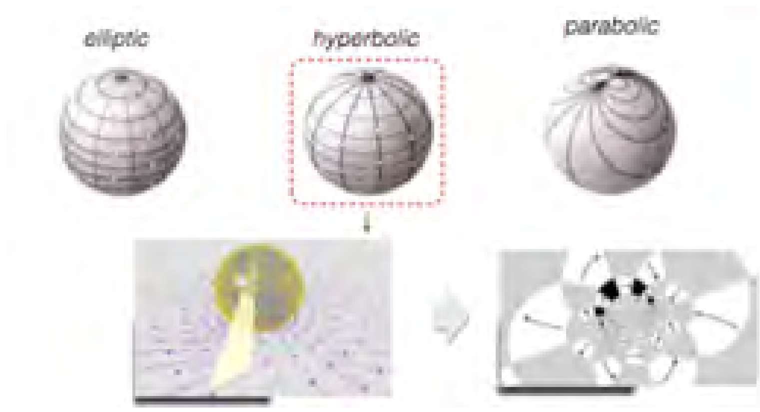


Figure 5: Canonical Moebius transformations.

The Moebius Transformations are defined as mappings on the extended complex plane, which correspond to the Riemann Sphere. Hence, these transformations constitute the natural mathematical basis to operate with omnidirectional images. Furthermore, we can verify that the canonical Moebius Transformations have a direct correspondence with camera movements in VR, except camera translation, which cannot be performed by an image transformation. That is, the pan/tilit movements correspond to the elliptic transformation, while zoom corresponds to the hyperbolic transformation. We conjecture that the parabolic transformation affects the perspective relations.

- Omnidirectional Images and Moebius Transformations
  - Pan/Tilt $\leftrightarrow$ Elliptic Transformation
  - Zoom $\leftrightarrow$ Hyperbolic Transformation
  - Perspective $\leftrightarrow$ Parabolic Transformation ?

6 The Moebius Transformation

We used a similar model from [4].

Definition 1. *The mapping* $S : \mathbb{C}_\infty \to \mathbb{C}_\infty$ *in the form* $S(z) = \dfrac{az+b}{cz+d}$ *is called a linear fractionary transformation. If* a, b, c *and* d *satisfies* $ad - bc \neq 0$ *then* S *is called a* ***Moebius Transformation****.*

6.1 Computation Pipeline

The Moebius Transformation computation for omnidirectional images represented in the equirectangular format can be performed in a sequence of steps described as in Figure 6

Figure 6: Computation pipeline.

In this sequence, the image is mapped from the latitude/longitude parametrization to the Riemann Sphere and then to the extended complex plane where the transformation takes place. Subsequently, the inverse mappings is applied.

First, we align the z-axis with the camera axis. Let $\mathbf{M^T}$ be the transpose matrix of the transformation matrix corresponding to the translation, rotation and scaling of the camera. Then the first transformation is given by

$$\mathbf{A} : \mathbb{S}^2 \to \mathbb{S}^2$$
$$(x_0, y_0, z_0) \mapsto \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \mathbf{M^T} \times \begin{pmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{pmatrix}$$

We then project the sphere to the complex plane using the stereographic projection:

$$\mathbf{SP} : \mathbb{S}^2 \setminus \{(0,0,-1)\} \to \mathbb{C}_\infty$$
$$(x, y, z) \mapsto (u, v) = \left(\frac{2x}{z+1}, \frac{2y}{z+1}\right)$$

Then we can rewrite the position coordinates in polar form:

$$u + iv = (u, v) \mapsto (r, \theta) = (\sqrt{u^2 + v^2}, arctan2(u, v)) = re^{i\theta}$$

In the case of zoom, the hyperbolic transform corresponds to the complex multiplication:

$$(r, \theta) \mapsto (\tilde{r}, \tilde{\theta}) = (rs, \theta + \alpha)$$

Where $s \in \mathbb{R}$ is the scale, i.e., zoom and $\alpha \in \mathbb{R}$ the rotation's angle of the Moebius Transformation. We then return to the cartesian form

$$(\tilde{r}, \tilde{\theta}) \mapsto (\tilde{u}, \tilde{v}) = (\tilde{r}\cos\tilde{\theta}, \tilde{r}\sin\tilde{\theta})$$

and return to the sphere using the inverse of the stereographic projection:

$$\begin{aligned} \mathbf{SP}^{-1} : \mathbb{C}_\infty &\to \mathbb{S}^2 \setminus \{(0,0,-1)\} \\ (\tilde{u},\tilde{v}) \mapsto (x_f, y_f, z_f) &= \left(\frac{\tilde{u}\cdot(1+z_f)}{2}, \frac{\tilde{v}\cdot(1+z_f)}{2}, \frac{\tilde{u}^2+\tilde{v}^2-4}{\tilde{u}^2+\tilde{v}^2+4} \right) \end{aligned}$$

Finally, we return the sphere to its initial position:

$$\begin{aligned} \mathbf{A}^{-1} : \mathbb{S}^2 \setminus \{(0,0,-1)\} &\to \mathbb{S}^2 \\ (x_f, y_f, z_f) \mapsto \begin{pmatrix} x_m \\ y_m \\ z_m \\ 1 \end{pmatrix} &= \mathbf{M} \times \begin{pmatrix} x_f \\ y_f \\ z_f \\ 1 \end{pmatrix} \end{aligned}$$

6.2 Some Results Related to VR

In this subsection, we present some results about Moebius Transformations that are related to Virtual Reality.

6.2.1 Scale factor to map one FOV to another

Considering the hyperbolic Moebius Transformation $z \mapsto Kz$, we deduce the scaling factor K that causes the result of mapping one field of view to another. Since Moebius Transformations are conformal, i.e., maps circles to circles, and our problem have radial symmetry, it is sufficient to calculate the factor K between to map the point $\left(\frac{\theta_1}{2}, 0\right)$ to the point $\left(\frac{\theta_2}{2}, 0\right)$ on the equirectangular domain.

We use the following definition of the stereographic projection:

$$\begin{aligned} \mathbf{SP}' : \mathbb{S}^2 \setminus \{(-1,0,0)\} &\to \mathbb{C}_\infty \\ (x,y,z) &\mapsto \left(\frac{2y}{x+1}, \frac{2z}{x+1} \right) \end{aligned} \tag{2}$$

Using (1) to rewrite (2) in the equirectangular format, we obtain:

$$(\lambda, \phi) \mapsto (u, v) = \left(\frac{2\sin\lambda\cos\phi}{1+\cos\lambda\cos\phi}, \frac{2\sin\phi}{1+\cos\lambda\cos\phi} \right)$$

Using the simplification above, the problem reduces to:

$$\left(\frac{\theta_1}{2}, 0\right) \mapsto (u_1, 0) = \left(\frac{2\sin(\theta_1/2)}{1+\cos(\theta_1/2)}, 0 \right)$$

and

$$\left(\frac{\theta_2}{2}, 0\right) \mapsto (u_2, 0) = \left(\frac{2\sin(\theta_2/2)}{1+\cos(\theta_2/2)}, 0 \right)$$

If we want to map the point $(\theta_1/2, 0)$ to the point $(\theta_2/2, 0)$ we need to satisfy the following:

$$\begin{aligned} Ku_1 &= u_2 \\ K\left(\frac{2\sin(\theta_1/2)}{1+\cos(\theta_1/2)} \right) &= \frac{2\sin(\theta_2/2)}{1+\cos(\theta_2/2)} \end{aligned}$$

But this implies that:

$$K = \frac{\sin(\theta_2/2)}{\sin(\theta_1/2)} \cdot \frac{1+\cos(\theta_1/2)}{1+\cos(\theta_2/2)} \tag{3}$$

This result provides us a way to display a θ_1 (longitudinal) field of view into a θ_2 (longitudinal) window. As the hyperbolic transformation is proportional, this result holds for the latitudinal field of view as well. Figure 7 illustrates our result.

Figure 7: Top: Input image, "termini equirectangular" by Flickr user Luca Biada; The blue square shows 60°/60° FOV, while the red square a 90°/90° FOV and the green one a 135°/135° FOV. Bottom: results after applying $z \mapsto Kz$ to map the different FOVs to 90 degrees and then applying the perspective projection. Bottom Left:60°/60° FOV mapped to 90°/90° FOV, $K = 1.54$. Bottom Middle: 90°/90° FOV. Bottom Right: 135°/135° FOV mapped to 90°/90° FOV, $K = 0.61$.

6.3 Comparison Between Perspective and Moebius Scaling

Using our previous result, we can easily generate a comparison between Moebius and Perspective Projection in zoom in and zoom out effects. In Figure 8 the result can be seen using the same idea from the previous result, projecting a field of view into a 90 degree square in perspective projection. For fields of view narrower than 90 degrees, the perspective projection is well behaved (8a), while the Moebius-perspective projection bends objects (8b). But for angles greater than 90 degrees, perspective projection stretches objects unnaturally (8c), while the Moebius-perspective projection preserves their shape very well (8d). For angles much larger than 90 degrees, the perspective projection is unusable (8e). In the case of the Moebius-perspective projection the shapes of the objects are well preserved, but straight lines are not preserved satisfactorily (8f).

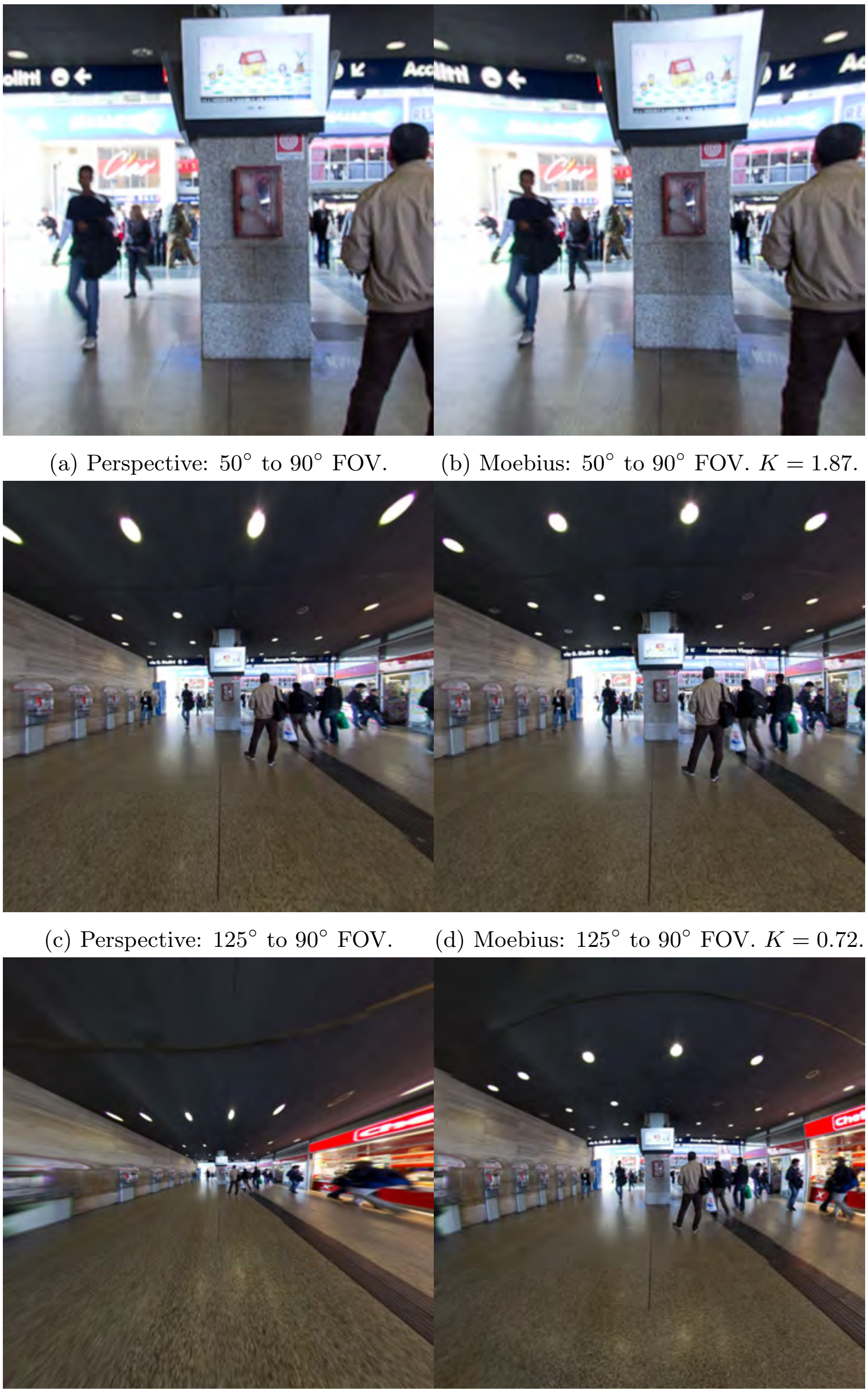
7 GPU Implementation

To process the Moebius transformation in real time on videos or even panoramic images, we developed a shader that takes advantage of the equipment's graphic hardware used for visualization (NVIDIA GPU). This shader is associated with the rendering of the sphere.

We used the Unity game engine and HDM Gear VR as platforms for our experiments. Typically, we implemented videos or panoramic images visualization in VR creating a scene in Unity, with a sphere and a camera centered in the origin of the scene. The observer's point of view is defined at run time by the rotation of the HMD to which the camera is associated.

In the case of videos, we also included in the scene a Unity object called Video Player that controls video projection by the sphere renderer.

The shader processes the vertices of the sphere mesh, returning a new position for each vertex,



(a) Perspective: 50° to 90° FOV. (b) Moebius: 50° to 90° FOV. $K = 1.87$.

(c) Perspective: 125° to 90° FOV. (d) Moebius: 125° to 90° FOV. $K = 0.72$.

(e) Perspective: 160° to 90° FOV. (f) Moebius: 160° to 90° FOV. $K = 0.49$.

Figure 8: Comparison between perspective and moebius-perspective projection. All results are projected into a 90° by 90° square.

resulting from the Moebius transformation. On this resulting mesh, Unity maps the images, applying the corresponding distortions.

The zoom transformation can be set in relation to a direction in the panoramic image or with reference to the viewer's line of sight.

In the first case, the transformation is calculated at a fixed point on the sphere. Our shader receives as parameters the values of scale and rotation to be applied in the transformation of Moebius and the panoramic image.

For each vertex of the object mesh, the shader applies the previously described calculations and returns the transformed vertices. The colors that the shader returns are those found in the corresponding position in the panoramic image.

In this case, the observer notices the natural effect of zooming and rotating when his axis of vision is aligned with the axis used as a reference for the transformation. As the scale transformation is applied to the entire surface of the sphere, one perceives a natural zoom at the point of reference of the transformation, but the further away from this point, the greater the distortion perceived by the observer.

In the second case, in order for the transformation reference point to coincide with the observer's point of view, we chose to calculate a rotation matrix and pass this matrix to the shader as the input parameter. The shader uses this matrix to apply a rotation at the vertices, aligning the observer's axis of view with the reference axis of the Moebius transformation calculations, to then apply these calculations. By doing so, the zoom effect is always perceived from the observer's point of view.

The image used was captured by a Lady Bug camera from Point Gray. To make it easier to debug the zoom algorithms at run time, we included markers in the image using Adobe Photoshop and also a virtual HUD indicating the zoom and coordinate values of the point of view and a cross indicating the position of the point of view in the view.

8 Perceptual Tests with the Moebius Zoom

As we mentioned, we understand that there should be limits to the zoom scale values, depending on the aperture in the viewing angle that each HMD offers. In our tests we will determine these limits by using the zoom with a variety of people and HMDs.

Since VR zoom is a global transformation in the viewing sphere, the magnification or reduction of the observed region also distorts the remainder of the projected image of the sphere. The greater the distortion, the further it moves away from the point of view, the center of transformation. In a zoom-out, while increasing the effect and distance, there comes a time when geometry distortions of the objects in the scene become apparent. In the zoom-in, fortunately, the distorted region starts off the visual range and gets progressively further away from the field of view by increasing the zooming effect.

Once we establish the limits that prevent the perception of distortion of the images, we must also determine the range of values in which the zoom causes a narrative effect and that at the same time is not consciously perceived by the observer. This feature can be used, for example, to enhance the reaction of a character, or even to direct the viewer's attention to a particular object or region of the scene, at the moment he looks at this object or region of interest. The highlight of this object or region generated by the zoom can attract the attention and focus of the viewer, but if it is exaggerated, the viewer can perceive the artificial movement of the image, interrupting its immersion.

Another phenomenon that we must deal with is the sensation of movement when the zoom is out of the neutral value. For both zoom-in and zoom-out, the viewer experiences a sense that the rotation of the world around them is faster (in zoom-in) or slower (zoom-out) than usual. It is the same sensation you have when using a binocular in the normal or inverted position and moving the head. Again, in this case, we must find the limits of values in which this phenomenon is not perceptible.

8.1 Perception of Image Distortions

As previously described, in zoom-in based on the Moebius transformation, the image geometry remains intact regardless of the approximation effect values. Zooming out from a view already processed by the zoom-in also does not create distortions until it reaches the neutral value (original view state).

On the other hand, zooming out generates progressive peripheral distortion by increasing the distancing effect from the original view. These distortions can best be noted by observing the moment that straight lines within the field of view begin to curve. In more "organic" scenes where there are missing straight lines, it is possible that the zoom-out may assume greater distancing values than in scenes with the presence of straight lines.

8.2 Correspondence with Movements

In our tests, we realized that the effect of moving from the observer's point of view when applied to the zoom may not be natural, depending on the degree of scale applied. Without zooming or zooming in neutral, movement of the observer's head results in a natural movement from the point of view, as if it were accompanying the movement of the head in synchronism.

From a certain scale value limit, either to magnify or to reduce, the image motion no longer naturally accompanies the observer's head movement, producing an effect similar to moving the head using a binocular.

To understand the natural limits of scale, we created an application with zoom control by the observer and recorded the zoom values in which the user perceives the movement of the image as natural in relation to the movement of the head.

9 Experiments and Narrative

We also carried out experiments to produce effects for cinematographic narrative. In this sense, one aspect to be considered in zooming is its form or application dynamics, which basically corresponds to how to define the value of the scale to be used in the calculation of the Moebius transformation.

In our experiments, we have created two ways of defining the scale value to be applied in zoom: controlled or preset. The controlled scale is one in which the observer defines the value of the scale at runtime, using a control bound to the HMD. The preset scale is one in which the scaling value for each point in the image is set at production time.

The model in which the scale is controlled by the observer seems to us uninteresting from the point of view of narrative. This control was used to help us define the value limits we discussed earlier. However, surrendering the zoom control to the viewer poses a risk of immersion or distraction breaking and has no meaning in the narrative unless, as part of the story, the viewer is wearing a visual equipment that has zoom controlled by him.

In the case of a predefined scale, we implemented two experiments: the first using reference points with previously assigned scale values and the second using a zoom map whose gray tone at each pixel corresponds to the scale values.

In the first (using reference points), the value of the scale at the point of view is calculated by the mean of the values associated with the reference points, weighted by the inverse of the geodesic distances from the point of view up to these points.

In the case of the zoom map, we created an image in which each pixel has a shade of gray that represents the value of the scale in that position. At run time, we calculate the coordinate of the pixel corresponding to the point of view of the observer in the image and thereby define the value of the scale as a function of the grayness of that coordinate in the zoom map. To create the zoom map, we use Photoshop and paint a layer on the panoramic image that is actually visualized. The resolution and dimensions of the zoom map are independent of the dimensions and resolution of the image being viewed.

Both approaches have advantages and disadvantages depending on the application. The assignment of values to a set of points is not very intuitive, but may facilitate a possible dynamics of displacement of these points, in case the object of interest is moving. The zoom map is made in a much more natural way, but presents a greater effort in case the zoom has to accompany a moving object, because instead of a map it is necessary to create an animation (map sequence).

Another special application for VR zoom is to simulate the traveling effect, allowing a potential increase in the immersion sensation by providing the perception of image movement corresponding to the viewer's head displacement. In VR, the center of the viewing sphere follows the position of the HMD. Shifting the center of the viewing sphere relative to the position of the HMD creates problems, especially in relation to the distortion of the image with the turning of the head. Then, as the sphere accompanies the movement of the observer's head, it does not alter the projected image on the sphere. As a consequence, a person leaning over to see an object more closely perceives the image, as if it had not gotten closer. Because it is not a natural phenomenon, it also represents a break in immersion.

This immersion break can be solved by applying a zoom whose scaling is controlled by the HMD translation motion. If the observer moves his head to get closer to an object in the scene, as we increase the scale in his point of view, we create the illusion that the object has become closer. The restriction of this solution is precisely the limit at which the scale causes an artificial sensation of image movement as the head rotates, as we shall see below.

Since the Gear VR does not capture translation motion, the scrolling effect can be triggered by manual control, which is not a natural experience. Already with the Oculus Rift, we can have a moderate catch of head translation movement. In the case of a HTC Live, where the user can move around in a larger space, the traveling effect becomes a bigger challenge. If the scene contains relatively distant objects of interest, the lack of parallax would create a cognitive problem.

10 Conclusion

Among the resources of the cinematographic language, we explore the effect of zoom in VR as a possible tool to support the narrative. We suggest zooming based on Moebius transformation, addressing both the quality aspects of the resulting image and the forms of application dynamics.

We consider that the zooming based on the Moebius transformation is suitable for VR, generating results that are perceived as natural to the observer, respecting limits of scale values that depend on the type of application that is desired and also the type of HMD used. Beyond these limits, the distortions generated represent a risk to the quality of the image and other fundamental factors to immersion.

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