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Generalized Projection for Yamato-e and Ukiyo-e with Projection Reference Plane

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ABSTRACT

Yamato-e and Ukiyo-e style are Japanese traditional painting styles that have two characteristics, linearity and verticality. We propose a novel generalized projection method to produce such images using 3D computer graphics. The method enables orthographic, perspective, reverse perspective, oblique projections, and a projection with a different field of view vertically and horizontally. The key idea is to control the tilt angles of four-sided planes of a view volume indirectly and independently with the *projection reference plane*. It can be applied easily to user interactive CG creating tools, and it can produce pseudo multi-perspective projected images. We can see them from our implementation and the resultant images.

CCS CONCEPTS

• **Computing methodologies** → *3D imaging*; *Non-photorealistic rendering*;

KEYWORDS

projection transformation, perspective, orthographic, oblique, reverse perspective, view volume, *Yamato-e*, *Ukiyo-e*, multi-perspective, user interface

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1 INTRODUCTION

Drawing and painting, which are actions to transform three dimensional space into a two-dimensional plane, are forms of artistic expression that have been performed since ancient age. In the West, a perspective projection technique was established in the Renaissance, and paintings began to be made in a geometrically correct way. On the other side of the planet, a unique style of painting called Yamato-e style was established in Japan for narrative scrolls. As a story progresses on a scroll, the viewing part of a very wide painting on the scroll is moved by the viewer. Therefore, oblique projections, which do not have a vanishing point, have been developed. Please refer to [9] for Yamato-e projections.

It is said that the Western geometric perspective drawing was introduced to Japan in the middle of the 18th century, and this perspective was called "Uki-e". A Uki-e boom started because drawing of a complete reproduction of a perspective view had a great immersive impact on the viewer. However, such geometrically correct perspective declined, and Ukiyo-e became popular instead. This art form utilized a mixture of projection techniques such as incomplete perspective projection, orthographic projection, and bird's-eye view oblique projection, which were the traditional techniques in Yamato-e[6]. Although Ukiyo-e is incomplete as a viewing projection image, it expresses depth and follows formalized rules that are linearity and verticality. Linearity is a constraint where any straight line in 3D has to be drawn as a straight one in an image. Verticality is a constraint where any vertical line in 3D has to be vertical one in an image. In this paper, we extend the conventional projection pipeline in 3D graphics to make it suitable for Ukiyo-e and Yamato-e style projections.

In typical 3D graphics tools, one parameter, field of view (FoV) is provided to control the projection of a scene. In contrast, we provide four parameters for projection. These parameters allow setting the tilt angles of four-sided planes of a view volume independently with the *projection reference plane*[14]. Using these four parameters, we extend the expressiveness of a simple projection pipeline widely used in 3D computer graphics to accept Yamato-e and Ukiyo-e style.

2 RELATED WORK

Kubo et al.[7] mentioned Ukiyo-e projection in the context of multi-perspective projection[3, 10, 13]. However, the characteristics of linearity and verticality are not explicitly discussed. Those multi-perspective projection techniques are based on projections of multiple points of view like cubism, and they do not preserve the linearity of lines in a scene. Our method does not allow multiple points of view, but relaxes the usual perspective projection used in 3D graphics a little.

Several methods[1, 2, 8, 14] integrate perspective, orthographic, and reverse perspective projections. These extend the meaning of FoV and preserve the linearity. The temporal screen used method by Osa et al.[8] enabled integration in

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the way of ray-tracing with a pseudo screen and a parameter to move the ray starting point from the camera origin. This screen works as a *projection reference plane* proposed in [14]. However, this method does not support oblique projection. The focal length based method by Baba et al.[1] utilizes a focal length with a range from $-\infty$ to ∞ as the parameter to integrate perspective, orthographic, and reverse perspective projections, and it also considers oblique projections. A subset of this method was also presented in [2]. However, it does not handle interactive controllability for a user to obtain expected projected views. We have developed a FoV-based method[14], which was designed to produce Ukiyo-e and Yamato-e style images with 3D models, and it also integrates all projections supported in[1]. It adopts three continuous parameters, one for FoV and two for horizontal and vertical shearing, to control the form of a view volume while introducing the *projection reference plane*, the intersection of which has a scene that is fixed in a rendered image while changing projection parameters. As the interactive projection control is taken into account, it should be the most appropriate for the interactive CG creation tools among the three methods. We will compare these three different parameterizing approaches from the usability point of view and then extend the best one by adding one more parameter.

3 COMPARISON OF FOV CONTROL

This section compares three approaches[1, 8, 14] to parameterize FoV from the point of view of interactive operability. Assuming that the size of a projected object in parallel projection is 1, its scaling factor, which is decided by the parameter for each method, can be calculated.

The scaling factor S_1 for the temporal screen projection-based method [8] is calculated using

$$S_1(\alpha) = \frac{p_3}{(p_3 - z)\alpha + z}, \quad (\alpha > 0), \tag{1}$$

where α is the parameter to control the FoV in the method, which is called the "reverse perspective projection parameter," and p_3 and z are the z coordinate value of the temporal screen and the object.

The scaling factor S_2 for the focal length based method[1] is calculated using

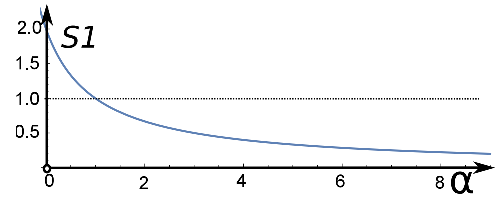
$$S_2(f) = \frac{f}{f + z}, \quad (f < 0, f > -z), \tag{2}$$

where f is the parameter to express the focal length for projection, and z is the z coordinate value of the object.

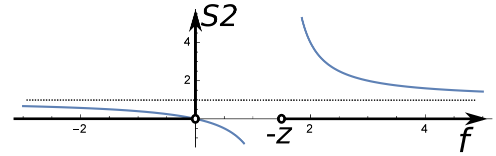
The scaling factor S_3 for the direct FoV control method[14] became a function of half horizontal FoV θ. Because we utilize $\tau = \tan\theta$ instead of θ as a parameter to express the FoV in this paper, S_3 is calculated using

$$S_3(\tau) = \frac{W + 2(\lambda + z)\tau}{W}, \quad \left(\frac{W}{2(\lambda - F)} < \tau < \frac{W}{2(\lambda - N)}\right), \tag{3}$$

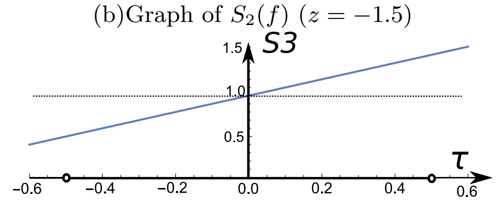
where λ is the depth of the PRP, F and N are the distances to the far- and near-sided planes of the view volume, and W is the width of the PRP.



(a)Graph of $S_1(\alpha)$ $(z = 1.5, p_3 = 3)$

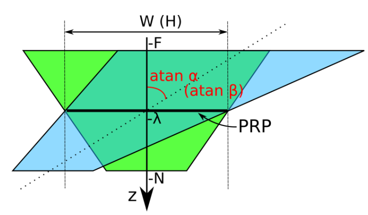


(b)Graph of $S_2(f)$ $(z = -1.5)$

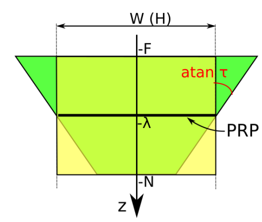


(c)Graph of $S_3(\tau)$
$(W = 1, N = 1, \lambda = 2, F = 3, z = -1.5)$

Figure 1: Comparison of scale factor



(a) α (β)controls the shear angle of the view volume horizontally (vertically)



(b) τ controls the horizontal FoV directly

Figure 2: Parameters

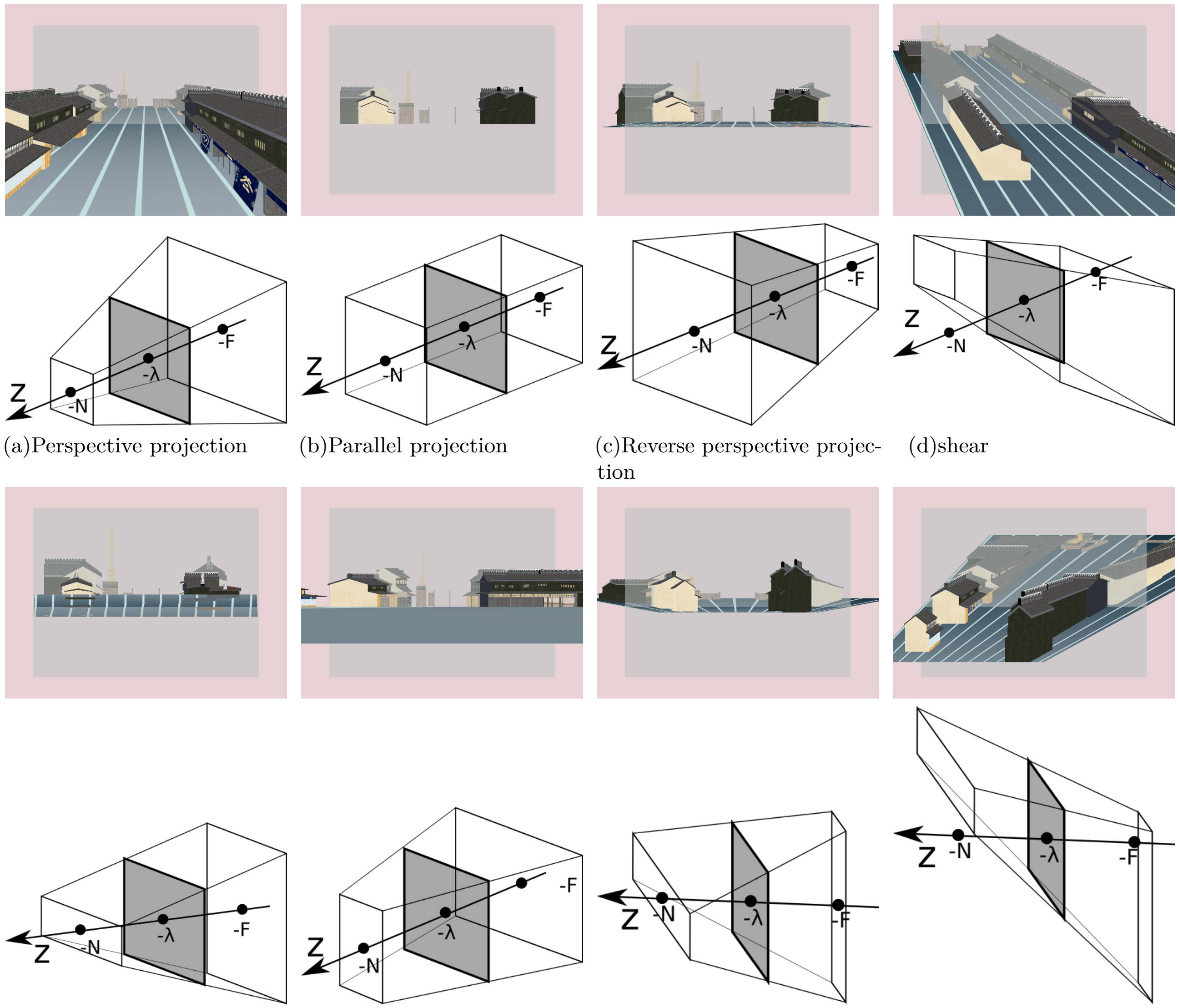
Figure 1(a), (b), and (c) are graphs of the scaling factors as functions of each parameter, where the target object is set at 1.5 units away from the camera origin. These figures show that the direct FoV control method has an advantage. Its scaled appearance changes constantly because S_3 is linear, whereas S_1 and S_2 are nonlinear. This means that when the user changes the parameter in our method, the rate of change in the appearance is constant, though those of other methods are not.

For this reason, our method appears to have better parameterization.

4 PROPOSED METHOD

4.1 Projection Transformation

Deforming a view volume enables controlling the projection while maintaining the linearity. Let the near and far faces of



(a)Perspective projection

(b)Parallel projection

(c)Reverse perspective projection

(d)shear

(e)Vertical perspective projection and horizontal parallel projection

(f)Vertical parallel projection and horizontal perspective projection

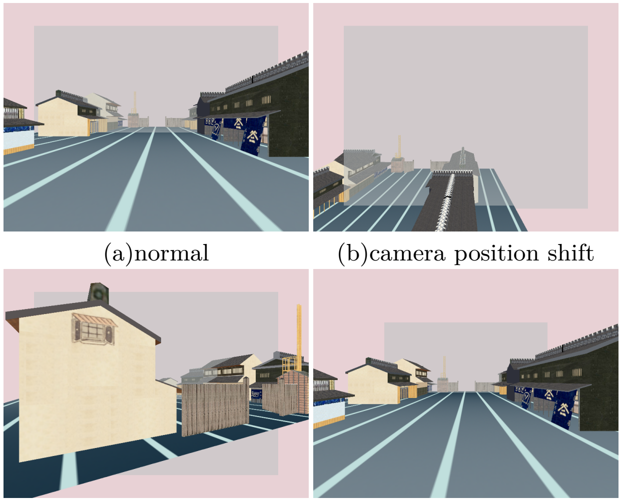
(g)Vertical perspective projection and horizontal reverse perspective projection

(h)Separated FoV projection with shearing

Figure 3: Projections and the corresponding view volumes

a view volume be parallel to the screen, that is, perpendicular to the z-axis with constant depths, and let a rectangular plane that is also parallel to the screen be placed between them with a depth λ. This rectangular plane is the *projection reference plane*(PRP). The four-sided planes of the view volume touch with the four sides of the PRP. In the method of [14], three parameters that are half FoV θ, the horizontal shearing α and the vertical shearing β (see Figure 2(a)) decide the tilt angles of those sided planes. In this paper, we set $\tau = \tan\theta$ as a parameter for FoV (see Figure 2(b)) for the linearity of the parameter mapping described in the previous section. View volume is deformed with the next projection matrices:

$$
\begin{aligned}
P_1 &= \begin{pmatrix} \frac{1}{\tau} & 0 & 0 & 0 \\ 0 & \frac{W}{H\tau} & 0 & 0 \\ 0 & 0 & -\frac{f_1+n_1}{F-N} & -\frac{2f_1n_1}{F-N} \\ 0 & 0 & -1 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & \alpha & \alpha\lambda \\ 0 & 1 & \beta & \beta\lambda \\ 0 & 0 & 1 & \lambda-\frac{W}{2\tau} \\ 0 & 0 & 0 & 1 \end{pmatrix}, \\
P_2 &= \begin{pmatrix} \frac{2}{W} & 0 & 0 & 0 \\ 0 & \frac{2}{H} & 0 & 0 \\ 0 & 0 & -\frac{2}{F-N} & -\frac{F+N-2\lambda}{F-N} \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & \alpha & \alpha\lambda \\ 0 & 1 & \beta & \beta\lambda \\ 0 & 0 & 1 & \lambda \\ 0 & 0 & 0 & 1 \end{pmatrix}, \\
P_3 &= \begin{pmatrix} -\frac{1}{\tau} & 0 & 0 & 0 \\ 0 & -\frac{W}{H\tau} & 0 & 0 \\ 0 & 0 & -\frac{f_3+n_3}{F-N} & \frac{2f_3n_3}{F-N} \\ 0 & 0 & -1 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & \alpha & \alpha\lambda \\ 0 & 1 & \beta & \beta\lambda \\ 0 & 0 & 1 & \lambda-\frac{W}{2\tau} \\ 0 & 0 & 0 & 1 \end{pmatrix},
\end{aligned}
\tag{4}
$$



(a)normal (b)camera position shift (c)camera rotation (d)change PRP position

Figure 4: Camera operations

where W and H are the width and height of the *the projection reference plane*, N and F are the distances from the origin to the near and far planes of the view volume, $n_1 = N + \frac{W}{2\tau} - \lambda$, $f_1 = F + \frac{W}{2\tau} - \lambda$, $n_3 = -f_1$, and $f_3 = -n_1$. One projection transformation matrix P is selected from P_1, P_2, and P_3 in case of perspective projection ($\tau > 0$), parallel projection ($\tau = 0$), and reverse perspective projection ($\tau < 0$), respectively. These matrices ensure continuity at $\tau = 0$ with the transform from the homogeneous space to the 3D space.

In addition to the aforementioned projection by P, we added one more procedure to extend the projection's quality. It is inserted in advance of the projection by P, and after a transformation to a camera coordinate system. Assuming that a vector $(x, y, z, 1)^t$ is in a camera coordinate system, it is substituted for $(x, y + y(z + \lambda)s, z, 1)^t$, where s is a new parameter. This process works as the space is stretched and shrunken in the vertical direction as being further from PRP. With this deformation in the space and the projection transformation of P, the tilt angles of the top- and bottom-sided planes of the view volume can be changed. The parameter s enables the vertical FoV to be defined separately from the horizontal FoV. Using these four parameters, τ, α, β, and s, we can set the tilt angles for four-sided planes independently and can obtain more various forms of view volume, not limited in the frustum shape.

4.2 User Interface

We implemented a user interface that can intuitively determine the parameters introduced in Section 4.1. The gray transparent planes in Figure 3 and in Figure 4 indicate the depth of PRP. It fixes the appearance of its intersection to a scene and makes it easy for the user to control projection parameters[14]. Changing parameters is basically done using mouse gestures over the rendered image like in a dragging object operation. Because the algorithm is quite simple, the user can get a response in real time.

Changing the FoV affects the change in view seamlessly from (a) to (c) in Figure 3, which corresponds to the mode of P_1, P_2, and P_3. When the horizontal and vertical shearing parameters α and β are set to non-zero values, then a view like the one in Figure 3(d) is given. These can be produced by the method in [14]; however, Figure 3(e) to (h) are not. Our extension enabled them by allowing horizontal FoV and vertical FoV to be set independently. Changing parameter s produces an image with a horizontal projection that is parallel but with a vertical projection that is perspective (e) and vise versa (f), even with the pair of perspective and reverse perspective projections (g). (h) shows the combination of shearing and separated FoVs.

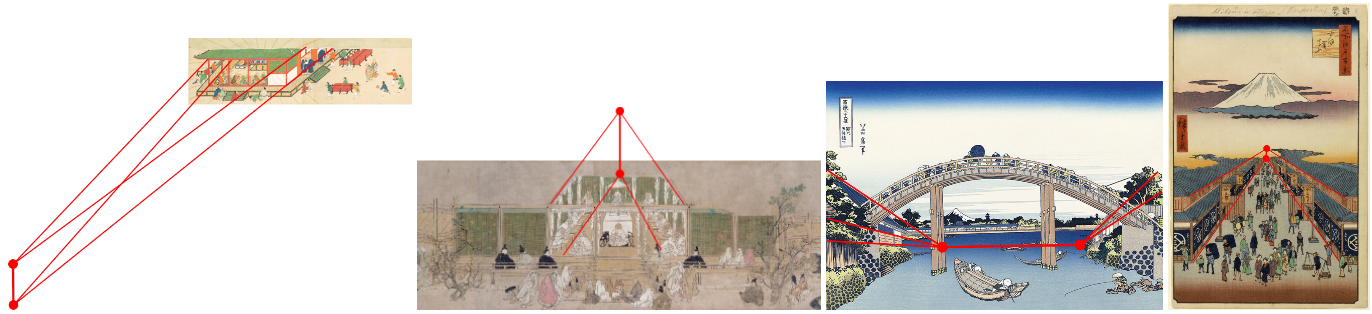
In addition to the these operations, the camera moves parallel with and visually perpendicular to the *projection reference plane*, the PRP centered rotation where the vertical direction is the rotation axis, and the PRP shift along with its perpendicular direction are also prepared as interactive operations. They affect the view illustrated in Figure 4. Their execution is performed in the transformation to the camera coordinate system. The projection explained in Section4.1 is executed after that. Note that the rotation axis is limited to the vertical. This ensures vertical lines in a scene are always projected into vertical lines on the screen.

5 RESULTS

Figure 5 shows Yamato-e and Ukiyo-e images whose vanishing point is not unique. Focusing on the building in Figure 5(a), you can see that a reverse perspective is used horizontally and that a parallel projection is used vertically. In Figure 5(b), perspective projection is used horizontally and parallel projection is used vertically. Figure 5(c) and (d) use perspective projection both horizontally and vertically, but the FoVs are different. Red lines represent feature lines of the projections. Figure 6 shows emulated images using our projection method. Actually, the crossing points of lines left parallel to the depth direction at the same x position in 3D space are not vanishing points but points with a depth of $-\frac{1}{s} - \lambda$. However, the resultant images are similar to images in Figure 5. In previous work, these images cannot be produced by one projection process. To obtain them, projections of parts of a scene need to be composed. In contrast, our method can produce using single projection. Therefore, we need to find a better composition in the constraint of Yamato-e and Ukiyo-e style.

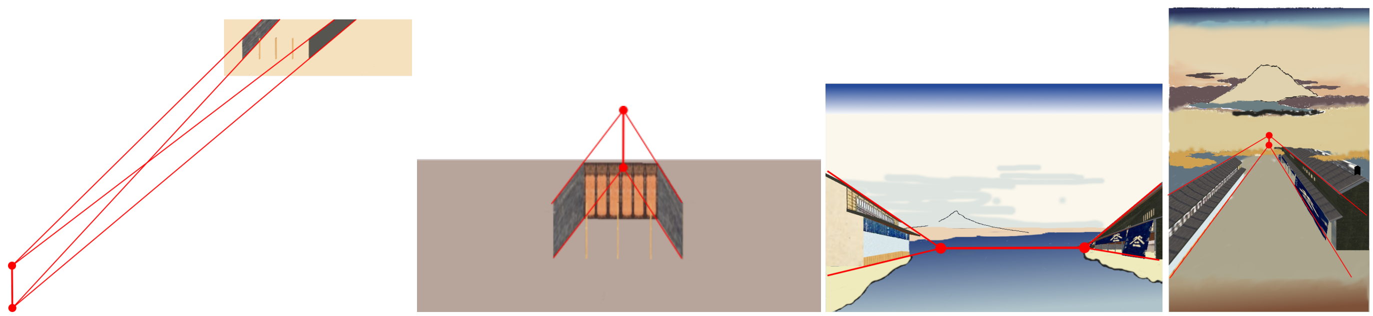
6 CONCLUSION AND FUTURE WORK

In this paper, we presented a generalized projection method that unifies various projections. It extends the expressiveness of 3D CG projections by allowing a non-frustum form as a view volume, and it can produce images as if there are multi-vanishing points are shown in Ukiyo-e. It also preserves linearity and verticality which are the features of Yamato-e and Ukiyo-e. Therefore, it creates Yamato-e and Ukiyo-e



(a)Picture of Xuanzang [11] (b)Picture scroll of Honen [12] (c)Under Mannen Bridge at Fukagawa [5] (d)Suruga-cho [4]

Figure 5: Examples of Yamato-e and Ukiyo-e



(a)image in reference to Figure 5(a) (b)image in reference to Figure 5(b) (c)image in reference to Figure 5(c) (d)image in reference to Figure 5(d)

Figure 6: Created images using our method in reference to Figure 5

style images better when they are created using 3D computer graphics.

We think that the application of this projection method is not limited to just creation of Yamato-e and Ukiyo-e style images because background paintings in hand-drawn animation are just one of the successors of the tradition of Yamato-e and Ukiyo-e. Developping new camera-work techniques with it for animation backgrounds might be interesting.

Applying this projection to an experiment to study human depth perception might also be interesting because it can produce images seamlessly in the range from viewing a correct one to a distorted one.

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