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BEFORE THE PATENT TRIAL AND APPEAL BOARD

3D Systems Corporation et al.,

Petitioner

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Intrepid Automation, Inc.,
Patent Owner.

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A New Edge Blending Paradigm For Multi-Projector Tiled Display Wall

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Abstract—Mutil-projector tiled display wall has been widely used in various applications such as simulation, entertainment. Edge blending, which is the core technology for mutil-projector tiled display wall, is improving by and by over ten years. But there are still some problems not resolved. Focus on optimizing edge blending and achieving perfect visual effect. we propose a new edge blending paradigm for the first time, which based on spline interpolation. We present that any couple of curves which can make the overlapped region be visual seamless could be the proper function model for edge blending. Because any discrete curve can be described by points, so we can use a group of control points to create the curve for edge blending, which is calculated through real-time spline interpolation. Comparing to the previous paradigm, our new paradigm is much more universal and flexible. Furthermore, it can realize perfect visual seamless edge blending and cost much less time than any method.

KeyWords—Simulation; edge blending; mutil-projector tiled display; visual seamless; spline interpolation; control points

I. INTRODUCTION

Mutil-projector tiled display wall creates immersive environment for visualization. Besides, it has many other advantages such as high-resolution, large field angle, low cost and so on. So in nowadays, Mutil-projector tiled display wall becomes more and more popular in visualization of simulation, especially in the fields of military simulation. For instance, cylinder display wall is always used in flight simulator.

The display technology of mutil-projector tiled display wall aims at resolving three problems: geometry calibration for image, color rectification of projectors and edge blending. As the core technology of mutil-projector tiled display wall, edge blending is always being the focus for academician in this field. R.Raskar[1] proposed a method called alpha-blending for edge blending, which was based on creating an alpha-mask for each projector and allotting intensity weight for every pixel of the image. Yang[2] improved the method by adding a factor called pixel-density and got a mathematical model of intensity weight for overlap region. P.Bourke[3] proposed an accurate function which could be linear or curving to get the intensity weight for overlap region. Gamma correction was also considered in Bourke's function. Finally, the alpha-blending method got an accurate mathematical model like this:

$$f(x) = \begin{cases} [a(2x)^p]^{\frac{1}{G}} & 0 \leq x \leq 0.5 \\ [1 - (1-a) \times (2(1-x))^p]^{\frac{1}{G}} & 0.5 \leq x \leq 1 \end{cases} \quad (1)$$

Recently years, except for the classical mathematical model of alpha-blending, some new mathematical models are being used in edge blending. Yang Tingjun[4] proposed that cosine function can be used to replace the classical mathematical model. In one patent literature of Zhejiang University^[5], a quarter of circular was used to be the mathematical model.

Previous work in edge blending mostly focused on improving Bourke's mathematical model. Although some creative ideas were proposed by Chinese academician recently, there are still some tough problems in the field of edge blending: Firstly, there is no intuitionistic connection between model parameters and luminance of the overlap region. Secondly, there is coupling Relationship among parameters. That means it will change the figure totally in whole interzone between 0 and 1 that if we adjust anyone of the parameters. Thirdly, the classical mathematical model of alpha-blending is lack of universality and flexibility.

Aiming to resolve such problems, we propose a new paradigm in which spline interpolation method is used to create a curve for edge blending. As we all know any discrete curve can be described approximately by a series of points. We use a group of points (we called them control points) $[P_1(x_1, y_1), P_2(x_2, y_2), \dots, P_n(x_n, y_n)]$ to divide the X interzone $[0, 1]$. Then an accurate mathematical model can be gotten by spline interpolation method based on the plane coordinates of those points $[P_1(x_1, y_1), P_2(x_2, y_2), \dots, P_n(x_n, y_n)]$. The figure of the mathematical model will be changed when changing coordinates of the points.

The rest of the paper is outlined as follows: In section 2, the new paradigm of edge blending is discussed; In section 3, implementation issues and the result of the new paradigm is described.

II. A PARADIGM BASED ON SPLINE INTERPOLATION FOR EDGE BLENDING

A. Principles On Choosing Mathematical Model

Previous principles on choosing mathematical model for edge blending will be like this[6]:

On the assumption that the luminance of a pixel X in the overlap region is $I(x)$, $I(x)$ lies on the sum of two projectors's outputs. For pixel X , supposing the luminance of projector 1 is $I_1(x)$, the luminance of projector 2 is $I_2(x)$. Supposing $f_1(x)$ is the mathematical model for projector 1, $f_2(x)$ is the mathematical model for projector 2. Then we get formula 2:

$$I(x) = f_1(x) * I_1(x) + f_2(x) * I_2(x) \quad (2)$$

Function $f_1(x)$ and $f_2(x)$ must meet constraint conditions:

$$f_1(x) + f_2(x) = 1, 0 \leq f_1(x), f_2(x) \leq 1 \quad (3)$$

Take the classical alpha-blending method for example, the previous principle is described as follows in Figure 1:

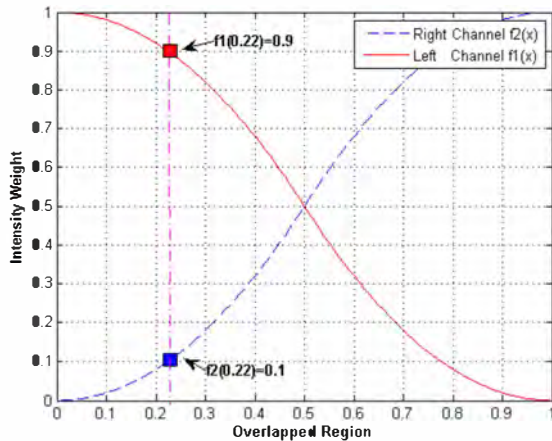


Figure 1. Function model on previous principle

It is obvious that $f_1(x)$ is the mirror of $f_2(x)$ in the interzone $[0,1]$. That means the mathematical model for edge blending should be symmetrical.

Previous principle is derived from the hypothesis that the two projectors have the same parameters whether in optical characteristic or in electronic characteristic. In fact, we can barely find a couple of projectors which are the same as each other totally. In this paper, we propose a new principle on choosing mathematical model for edge blending as follows: any couple of curves which would make the overlapped region be visual seamless could be the proper function model, whether they are symmetrical or not.

B. Mathematical description of the new paradigm

The key to edge blending is to find the proper curve as the mathematical model. Because once we have gotten the mathematical model, a series of intensity weight factors can be calculated for every pixel in the overlapped region. As we all know, any accurate mathematical model which is proper for edge blending can be approached by spline interpolation method. As can be seen in figure 2, any kind of curve can be created by spline interpolation.

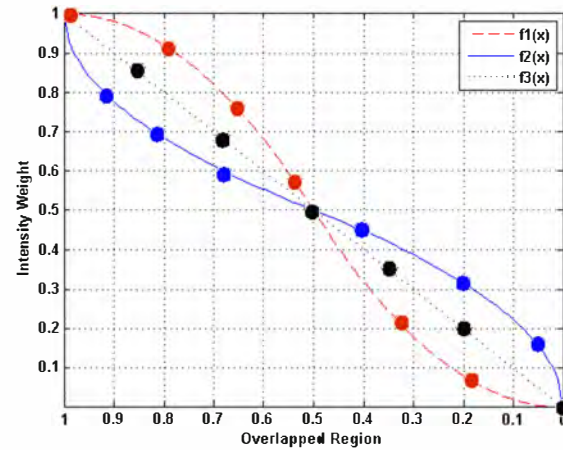


Figure 2. Curve creating using spline interpolation

Compared to other mathematical model, real-time calculation of the spline interpolation will be complex. But we just calculate when estimating the parameters of the for edge blending. Once we have found the final curve which is proper for edge blending. Then a table in which all the intensity weight factors are saved will be built offline for real-time rendering.

It is hypothesis there are a group of points $[P_1(x_1, y_1), P_2(x_2, y_2), \dots, P_n(x_n, y_n)]$, and the coordinate X of all the control points must be limited by following condition:

$$\pi: 0 = x_0 < x_1 < \dots < x_{n-1} < x_n = 1$$

Coordinate X of those points indicates the position of the overlapped region, then coordinate Y of corresponding point represents the intensity weight factor of the pixel which is at the position of the overlapped region. It is worth mentioning that coordinate Y should also be unitary too, because it would be nonsense for intensity weight factor if its value is out of interzone $[0,1]$.

Supposing that the order of the mathematical model we want to build is k , then a $n+k$ dimensional linear space can be represented like this:

$$\text{Span}\{1, x, \dots, x^k, (x-x_1)_+^k, \dots, (x-x_{n-1})_+^k\}$$

x_+^k will be defined as

$$x_+^k = \begin{cases} x^k & x \geq 0 \\ 0 & x < 0 \end{cases} \quad k = 1, 2, 3, \dots$$

Then a k orders spline function can be represented as:

$$y(x) = \sum_{j=0}^k a_j x^j + \frac{1}{k!} \sum_{j=1}^{n-1} c_j (x-x_j)_+^k, 0 \leq x \leq 1$$

$$a_j (j=0, 1, \dots, k) \quad c_j (j=0, 1, \dots, n-1) \quad (4)$$

,there are $n+k$ unknown parameters. According to the boundary conditions that $y(x)$ has $k-1$ order continuous derivative at every point in the interzone $[0,1]$:

$$y^{(r)}(x_i^-) = y^{(r)}(x_i^+) \quad i=1,2,\dots,n-1, r=0,1,k-1 \quad (5)$$

All the unknown parameters can be calculated from the formulas above. Then we derive a accurate function $y(x)$ like (4), which is going to be the proper curve for edge blending. Of course we can modify $y(x)$ just by changing the position of the control points, until $y(x)$ can make the overlapped region be visual seamless.

C. Guide-line of Real-time Adjusting

To find the proper function $y(x)$ of each projector for edging blending quickly and effectively, we need to pay attention to following points:

- It is very important to find the proper k for spline function $y(x)$. The larger k is, the smoother $y(x)$ is. $y(x)$ would be linear when $k=1$. But it will make adjusting be ineffective if the k is too large.
- Set the proper amount of control points n , which is confined as $n \in [2, 3, \dots, +\infty]$. It is worth noting that too many control points will make the adjusting complex and less effective. On the other hand, too less control points will result in lack of flexibility.
- Due to the exceeding sensitivity of human for color and luminance, we can use human vision as the feedback when finding the proper curve for edging blending. It is also very important to take an effective and intuitionistic way to change the control points real-time.

III. IMPLEMENTATION

In this section, we consider examples to compare our paradigm with other paradigms and to illustrate the advantages of the spline interpolation method for edging blending. Our system consist of three XGA (1024*768) LCD projectors running on Dawning A440r workstation. The 135° cylinder screen, whose radius is 3m and height is 2.3m, is divided in to three channels.

In this test, we compare the performance of three paradigms: a quarter of circular paradigm, classical mathematical model of alpha blending method and our paradigm based on spline interpolation.

Figure 3 shows the curves of the three paradigms. Figure 4, Figure 5 and Figure 6 shows the performance of each paradigms.

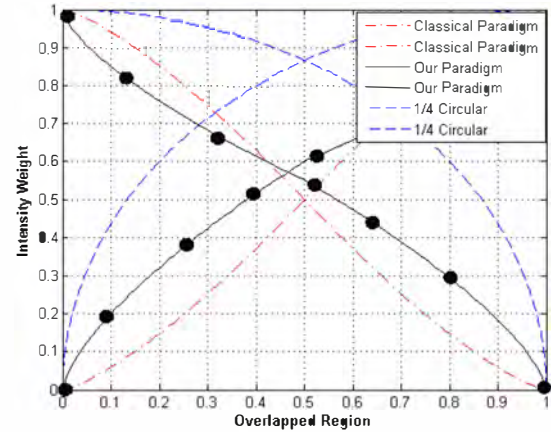


Figure 3. Curves description of three paradigm



Figure 4. Performance of a quarter of circular paradigm



Figure 5. Performance of classical method



Figure 6. Performance of our paradigm

As can be seen in Figure 4, Figure 5 and Figure 6, our paradigm make the blended luminance has no visible seam.

Contrast with previous paradigms, the advantages of our paradigm are:

- Universal: The core thought of the new paradigm is using points to describe curve. We do not need to find a specific function as mathematical model. A real-time curve is caculated as mathematical model by positions of the control points. So it is much more universal.
- Effective: Theoretically, A curve caculated by spline function can approach any function model we want. So it is much more effective to use spline function method than any other mathematical model.
- Directly: The process to make the overlap region seamless is much faster. Because this paradigm builds a direct connection between luminance of the overlap region and the parameters to be adjusted. We can directly change the position of control points to create any curve we want.
- Feeble Coupling Relationship: Unlike the classical mathematical model for edge blending, the parameters (coordinates of the control points) of this paradigm have feeble coupling relationship with each other. That means we can change part of the curve just by moving the corresponding point and make almost no influence to other part of the curve. In the classical mathematical model for edge blending, changing anyone of the parameters means changing the curve totally in whole interzone.

IV. CONCLUSIONS

In this paper, we have presented an edge blending paradigm for mutil-projector tiled display wall. The new paradigm based on spline interpolation realized visual seamless edge blending. Comparing with classical method, it has many advantages such as: more flexible on modeling, faster on adjusting and feeble coupling relationship. The new method based on this paradigm has been applied in several projections and National Invention Patent of China was applied.(Patent Application No. 200910086042.0, Patent Publish No.CN101571663;Another Patent Application No.201010168141.6) . Automatical edge blending system with the machine vision as feedback will be the focus in our future work.

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