PROJECTING IMAGE ON NON-PLANAR SURFACE WITH ZERO-TH ORDER GEOMETRIC CONTINUITY USING SIMPLE DUAL-LINEAR FUNCTION AND MANIPULATION OF STRICT INTEGER IMPLEMENTATION IN PROGRAMMING LANGUAGE

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ABSTRACT. Usage of a projection system to display large screen images is still relevant in the midst of LED-based display increasing popularity. This is due to that the system itself is a mature technology, reliable and cheaper than the LED counterpart. While various methods had addressed the projection problems on curve surface, projecting image on jagged like surface (zero order geometric continuity) has yet to be studied in depth. This paper proposes a method for projecting image on non-planar surface with zero-order geometric continuity property using parametric modeling. The method manipulate linear function by combining two functions into one by taking advantage of computer programs strict implementation of integer variables. The method was applied to grid-based texturing algorithm in order to create the desired zero-continuity effect on the surface. The method was compared with texturing that implement existing curve algorithm to project image on the screen. Visual evaluation results showed that the proposed method fared better compared to existing curve-based projection algorithm.

Keywords: projection system, non-planar surface, zero order geometric continuity surface

INTRODUCTION

Usage of a projection system to display large screen images is still relevant in the midst of LED-based display increasing popularity. This is due to that the system itself is a mature technology, reliable and cheaper than the LED counterpart. Its use is not only confined to displaying information but also being deployed for infotainment as can be seen in Rohith et al., (2013) and Chang & Huang, (2013). Given the context of infotainment, the current trends include infographics which display interesting graphics together with text (Koeman et al., 2014; Claes et al., 2013).

Constructing a projection system to suit the need for infotainment or infographics requires the innovative usage of the system. While this can be achieved by manipulating the image projections and transformation, an attractive result can also be produced by considering the surface whereby the projector system will be projected on. Current approach includes usage of a curved surface to display the image. Using this approach the image will appear bended and for some reason various research effort has been on this area including (You et al., 2000; Xu et al., 2005; Singh et al., 2012; Na et al., 2012; Burdis et al., 2012).

Besides curve surfaces such as discussed in Sun et al., 2012 there are also other types of surface including non-planar surfaces (Bimber et al., 2008). The non-planar surfaces specifically with ***Zero-Order Geometric Continuity (Z.O.G.C)*** can potentially be implemented to create creative display for a “corner-like” surfaces. Unfortunately modeling this type of non-planar area can be challenging due to the fact that it may involve piecewise function to produce a triangular shape. Usage of cosine or sine function may be complicated and resulting in undesired rounding. Fortunately, a programming language such as C++ has strict implementation of variables. In implementing integer variable for instance, the value would be stripped off its decimal value. Knowing this fact, we can use it to our advantage and create a linear equation to produce the zig-zag or triangular shape that is inherent in non-planar surface with Z.O.G.C. The following section will elaborate o literature reviews of related work. This is followed by section III whereby the methodology is revealed. Section IV reports experiments and result of the proposed method. Finally section V will conclude this paper proposal.

LITERATURE REVIEW

Projecting on a surface can be done with the help of texture mapping whereby a grid of polygon (plane) was mapped to a desired image. In this section, we will explain more on the texture mapping and such studies being conducted previously by various researchers.

Texture mapping is a method used to represent the surface details by excluding geometric complexity. For the past recent years, this method had been used in consumer-level graphic hardware. Wei (2004) introduced texture mapping method as an approach of representing fine details in models, since doing it with polygons would be in appropriate. The texture map was mapped onto the polygon. The polygon was then rotate or translates or projected with the texture map would be adjusted accordingly.

The texture itself comes with own coordinated space and would be mapped into the object or plane. OpenGL was usually utilized to do the texture mapping and drawing the primitives. The process involved loading the texture, bounding the texture to activate it, and for each polygon's vertices, they passed the texture coordinates and vertex coordinates (in object space) to the graphic system (Nikolov et al., 2004). Texture mapping done in Poullis et al. (2007) introduced a way of generating a composite texture map from a set of images. They did it by combining multiple images taken from various view-points. The combination was then set based on weight computed by different criteria. It was then packed to ensure computation time was reduced and improved the performance. This resulted in having a 3D model that stand alone with its texture that can be converted to various different applications. They did have multiple surfaces and each of it was projected into all the image planes that compute every area of the projected polygons. They choose the resolution by picking up the dimensions of the polygon with the largest area. The texture maps of the surface was the rendered by ray-tracing. It cast a ray from each point on the surface to the image planes to determine the point's color (Poullis et al., 2007).

Visualization performance was influenced by texture mapping process (Hua et al., 2004). It is a natural for the texture to have a large size that forced it to be stored in a slower external storage, rather than host memory. A research done by Hua et al. (2004) proposed a compact multi resolution model, Texture Mipmap Quadtree (TMQ). This was to present textures in large-scale size. It was fast loading. They introduced a dynamic texture management scheme based on two-level cache hierarchy to improve the performance of texture mapping.

Another study on texture mapping was done by Zhang et al. (2010) where they proposed a Discrete Texture Mapping for irregular surface. First the definition of texture mapping was explained as the texture image taken as input and maps into simple geometric shape. It was structured with the relationship between texture and object. The steps involved locating the coordinates of the point. Points were chosen with the least changing rate for horizontal and vertical gradient. Second steps were to find synchronized point between the horizontal and vertical. Then the RGB values of pixels in image space were mapped to produce a complete system.

The steps in Zhang et al. (2010) involved creating a grid for the plane. It was called Diamond steps to produce a grid matrix as a plane or surface. This step was done to compute the values of center points of each square of four dots, repeating the process to compute a value of points of the midpoints from every side of the square. As the grid was ready, the mapping process would start. The steps were to locate the image center. Then to divide the image into four sections and took the center as a boundary. Coordinates was calculated once mapping done. Then RGB values of pixels in image space were passed to the pixels in texture space. To enhance the three dimensional effect, lighting effects was added to the mapping result (Zhang et al., 2010).

Upon completion of the mapping process projectors were deployed to display the image. As shown in Sun et al. (2008) steps of projecting the images started by detecting the screen and projector's fiducials from camera images by parametric curve and surface lighting. It was then taken into quadrilateral mesh. Camera mapping was done by computing homography between each quadrilateral and its camera image. This created connection between camera and projectors mapping. A correct camera geometry by homography was captured. Two steps which were the screen-camera mapping and the projector-camera mapping would produce a set of screen-projectors mappings. The idea was to determine any points in the projector frame buffer and corresponding point on the screen. The proposed method did not cover image-to-projector mapping in this work as the scope was focusing on non-planar surface and not on the relation between camera, projector and screen mapping.

Xie et al. (2012) proposed a way of projections on non-planar surface by having an automatic correction for the image displayed on such surface. It involves Bezier patches to represents mapping from camera and projectors. Checkerboards pattern recognition and pixel-mapping concept will produce geometry registration for the projection's system. Two projectors used to projects the images and an intensity blending techniques would exclude the color difference and project a seamless correct display.

The proposed method would utilize grid-based texture mapping approach to create a deformable image. As the focus in proposing the single linear function for a non-planar surface with Z.O.G.C the paper would not cover other process such as homography (camera to projector mapping) or Bezier patches (use for spline modeling).

The following section elaborates on the proposed method.

RESEARCH METHOD

Texture mapping approach can also be used in producing custom projection system image. The existing method of texture mapping looked at usage of sine, cosine or spline based surface texture mapping. These methods may not be optimized for a situation where we have to project on non-planar surface with zero order geometry continuity (Z.O.G.C) property such as a wall corner or an intersection between the wall and the ceiling or the floor. The proposed method which will be known as Dual-Linear Method should be able to address this situation. Assuming the image is available, the proposed method can be broken down into the following steps:

Step 1: Construct Texture Plane using Grid approach.

Step 2: Map the Plane with The Image using the proposed Dual-Linear Method.

Step 3: Project the image on the surface.

In **Step 1**, a set of grid is constructed. The grid is a quadrilateral based grid. The selection of quad based grid is due to that the texture mapping using the grid is easier to process due to the rectangular nature of the image. Usage of triangular grid requires at least two polygons to form a grid instead of one (using quad).

In **Step 2**, the proposed Dual-Linear Method is being used to map the texture with the image. Dual-Linear Method takes advantage on the fact that programming language such as C language handles variables strictly. The integer variable in C Language only stores integer value whereby all the floating points value if available will be stripped out. E.g. a number 7.8 or 7.2 will be stored as 7 in an integer variable. The stripped value will not be considered for rounding at all.

A non-planar surface with Z.O.G.C in its primitive form can be divided into at least two planes. The z value which signifies the depth of the plane can be expressed in the form of linear function. Given the two planes, the linear function will have two different slope values. With this fact, the non-planar Z.O.G.C depth can be defined using a piecewise function as follows:

Let $p = \{\mathbb{R}: 0..1\}$ = the seed value for the line.
Let k = a determinant value
Let $midPt = (midPt_x, midPt_y)$ the point where the linear lines meet.

$$f = \begin{cases} p.\dfrac{midPt_y}{midPt_x} & p \leq midPt \\ p.\dfrac{-midPt_y}{1 - midPt} - \dfrac{-midPt_y}{1 - midPt_x} & p > midPt \end{cases} \quad (1)$$

The $\frac{-midPt_y}{1-x}$ can be rewritten as: (2)

$$\frac{-midPt_y}{1 - midPt_x} = \frac{(-1)}{(-1)} . \frac{(-midPt_y)}{(1 - midPt_x)} = \frac{midPt_y}{midPt_x - 1} \quad (3)$$

Rewriting (1) will produce:

$$f = \begin{cases} p.\dfrac{midPt_y}{midPt_x} & p \leq midPt \\ p.\dfrac{midPt_y}{midPt_x - 1} - \dfrac{midPt_y}{midPt_x - 1} & p > midPt \end{cases} \quad (4)$$

To form a uniform expression, we can introduce parameter k = 0 when $p \leq midPt$ and k= 1 when $p > midPt$. This will produce the following expression:

$$f = \begin{cases} p.\dfrac{midPt_y}{(midPt_x - k)} . \left(\dfrac{midPt_y}{midPt_x - k}\right)k & k \leq 0 \\ p.\dfrac{midPt_y}{midPt_x - k} - \left(\dfrac{midPt_y}{midPt_x - k}\right)k & k > 1 \end{cases} \quad (5)$$

k is calculated as follows with $\lfloor \square \rfloor$ indicates flooring the value to the nearest integer:

$$1 - \lfloor 1 - p + midPt_x \rfloor \quad (6)$$

With k is defined as in (6),expression (5) can be rewritten as a single function as follows:

$$f = \frac{midPt_y}{(midPt_x - k)} . (p - k) \quad (7)$$

EXPERIMENTS AND RESULTS

To establish how a curve-based texture performs against the proposed approach, six (6) images were prepared and projected on a corner of a wall (i.e, a non-planar Z.O.G.C surface). A visual comparison was done between the images. Visual inspection was a common approach to show the output of a projection method onto the screen. It was also used in Sajadi et al. (2010) and Bimber et al. (2007). As the main experiment was on visual inspection between the proposed method and the standard texturing method (sinusoidal), statistical comparison was not made in this research. Six images had been utilized in doing the comparison. Image 1, 2 and 3 had midpoints at the center of the image. Image 4 was a picture of a corner of a hall with the center of the corner coincides with the center of the image. Image 5 was a corner of a room. Like Image 4, the center of the image was slightly on the left. Image 6 on the other hand was also a picture of a corner at a café with the corner was slightly on the right (the pillar on the right). Comparison was done with sinusoidal based texture mapping; a common mapping that was used as the base whenever the subject of texture mapping was brought up. The following **Figure 1 – 6** shows the images used in the experiments.

Figure 1. Image 1

Figure 2. Image 2

Figure 3. Image 3

Figure 4. Image 4

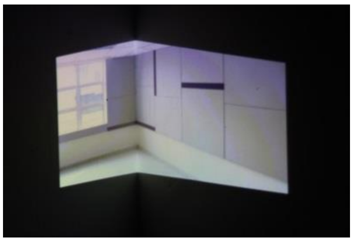

Figure 5. Image 5

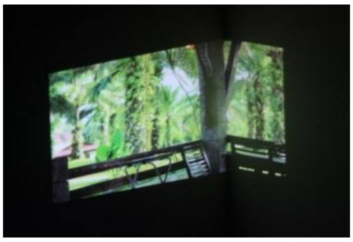

Figure 6. Image 6

The following Figure 7 to Figure 11 compares between utilizing sinusoidal mapping compared to Dual-Linear mapping as proposed by this paper.

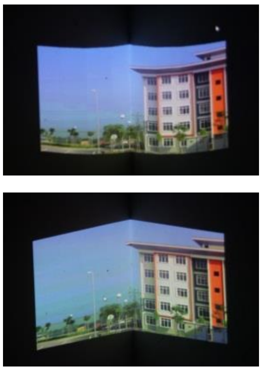

Figure 7. Projection (Image 1)
Above: Sine-based Mapping
Below: Proposed Dual Linear Mapping

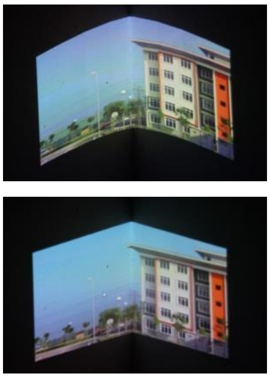

Figure 8. Increasing Depth Value (Image 1)
Above: Sine-based Mapping
Below: Proposed Dual Linear Mapping

Figure 9. Projection (Image 2)
Above: Sine-based Mapping
Below: Proposed Dual Linear Mapping

Figure 10. Increasing Depth Value (Image 2)
Above: Sine-based Mapping
Below: Proposed Dual Linear Mapping

Figure 11. Projection (Image 3)
Above: Sine-based Mapping
Below: Proposed Dual Linear Mapping

Figure 12. Increasing Depth Value (Image 3)
Above: Sine-based Mapping
Below: Proposed Dual Linear Mapping

It was apparent that trying to use sine or any curve-based function to handle non-planar surface with Z.O.G.C would produce a somewhat curvy image; a product that might not be desired. This was consistent throughout the produced images as shown in **Figure 7** to **Figure 12**. Shifting the corner (midpoint) area slightly off-center yielded interesting results as shown in the following **Figure 13** to **15**.

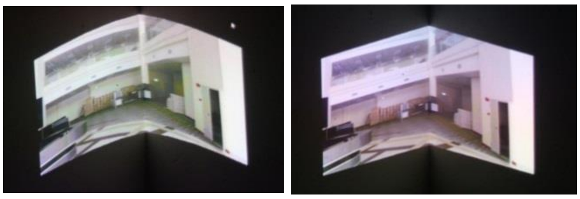

Figure 13. Projection (Image 4)
Left: Sine-based Mapping
Right: Proposed Dual Linear Mapping

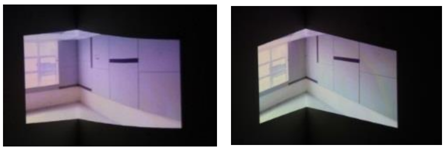

Figure 14. Projection (Image 5)
Left: Sine-based Mapping
Right: Proposed Dual Linear Mapping

Figure 15. Projection (Image 6)
Left: Sine-based Mapping
Right: Proposed Dual Linear Mapping

Based on the visual inspection of the above images, the proposed method outperforms the sine-based function. It was apparent in the picture that sine-based function projected unwanted curves when the projector was projected at the corner.

CONCLUSION

We present in this paper a method known as Dual Linear Texture Mapping to be used in a projection system in projecting image on a non-planar surface with zero order geometric continuity (Z.O.G.C) property. Adjusting the depth value in the proposed method did not bend the image unlike usage of curved function hence enable further enhancement for image to be displayed at non-planar surface with Z.O.G.C. We plan to further the research by incorporating depth estimation into the method so that the depth value can be further refined en route of producing better projected image.

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