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Protruded displacement mapping for image-based urban representation

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Abstract: This paper introduces a displacement mapping algorithm that represents protruded shapes on the surface of an object. Two verticalsurfaces that are perpendicular to the underlying surface are added along the boundary of the polygon surface in order to represent pixels overflowing acrossthe boundary of the polygon surface. The proposed approach can accurately represent the silhouettes of protruded shapes. Using per-pixel instructions on graphics hardware, the approach is accelerated and executed in real-time. The proposed method provides an effective solution for the representation of protruding shapes such as high-rise buildings in an urban environment which can be used in location based applications of mobile electronic devices.

Keywords: graphics library, image-based rendering, displacement mapping

Classification: Electron devices, circuits, and systems

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1 Introduction

Displacement mapping [1] has inspired several techniques to add details on a 3D object surface. Policarpo [2] proposed a hardware accelerated ray-tracer and Baboud [3] rendered objects on GPU as a collection of images with depth. Displacement mapping has historically been applied using depth field which expresses amount of interpenetration instead of height field as depicted in Fig. 1 (a). When the displacement map is applied to relief mapping [2], change of position in surface details is an unavoidable defect due to the sinking of the bottom surface. Note that the position of the grid on the yellow bottom surface in Fig. 1 (c) is moved down compared with Fig. 1 (b).

In order to express a protruded shape from the surface of an object without creating micro-polygons, rendered pixels that correspond to the surface detail must be located above the polygon that composes the object's surface. The rendered image should then be able to show the shape of the object protruding outward from the rendered polygons. Porumbescu [4] introduced shell mapping and Jeschke [5] extended it into curved shell mapping. Shell mapping can represent protruded shape, but this is inefficient to represent urban model in mobile devices because geometry texture should be built from polygonal model. We proposed modified relief mapping [6] to present urban buildings, but it does not completely deal with management of pixel overflow and steep displacement of protruding object.

This paper presents a straightforward approach to represent protruded shape on a surface with managing overflow of pixel across the boundary of a base surface.

2 Protruded displacement mapping

In contrast to interpenetration, the displacement overflows acrossthe boundary of a polygon should be representedfor the correct silhouette of a protruding object. In Fig. 1 (a), a cross-section of the displacement map representing a protrusion and the viewing direction from the point of view to the rendered pixel iscompared with the existing displacement map. The actual polygonal surface is located on the bottom of the cross-section of a height field. We define the displacement map as that the height of the bottom face of the protruded shape is 0, and the height of the top face is normalized 1. The base polygonal-surface is located where its height is 0. By this definition, the pixel to be rendered becomes A′ on the polygonal surface, and the actual color information that must be shown at A′ is P′. The position of point P′, at which the height map intersects with the viewing vector, must be found in order to render pixel A′. The value that is saved in the height map is inspected uniformly, from point B′, at which the viewing vector intersects the top face of the virtual volume, to point A′, the actual rendered pixel. Height values are inspected successively in order to find the intersection point between the viewing vector and the height map via a linear search. The inspection is stopped if the height value is smaller than the value saved in the height map at that point. After the linear search, in order to obtain a more accurate in-

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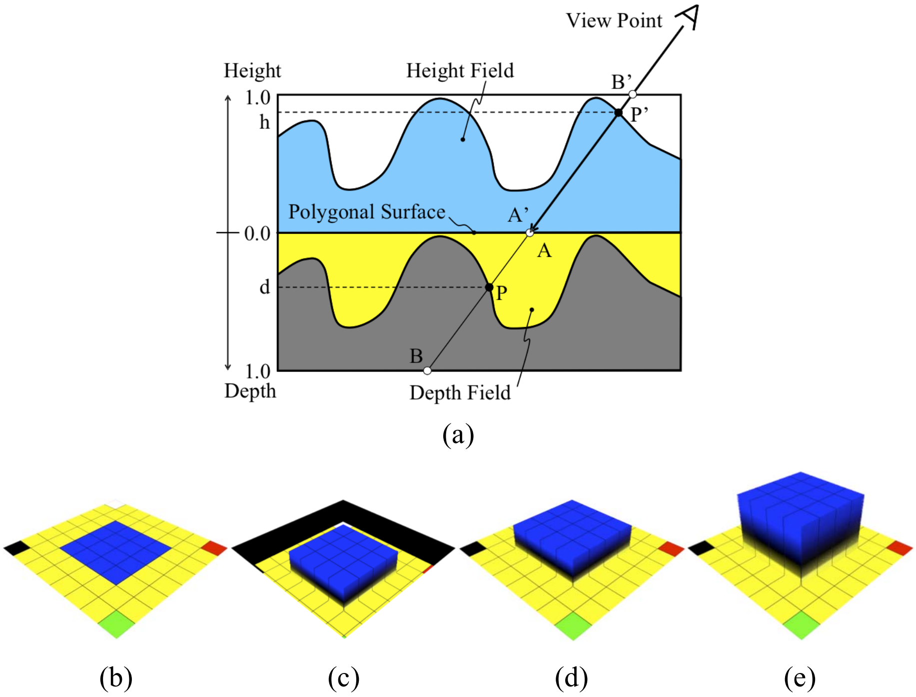

Fig. 1. PDM (protruded displacement mapping): (a) Bounding box of protrusion and interpenetration, (b) A quadrilateral rendered with texture map, (c) Relief mapping, (d) A quadrilateral rendered with protruded displacement map, (e) Complete PDM.

tersection point, the exact height of the intersection point is examined using a binary search.

If this method is applied to the same quadrilateral of Fig. 1 (b), the aspect of Fig. 1 (d) is achieved. The yellow ground marked with a grid pattern is a plane whose height is 0. Only the blue boxis protruded upward from the polygonal surface.

3 Displacement overflow

The overflow of pixels by displacement should be handled in order to represent the silhouette of the protruding shape over the polygon boundary. As the computation of PDM (protruded displacement mapping) is evaluated per-pixel, it is impossible to represent a protruding area located above the viewing vector E–V of Fig. 2 (a). For instance, to represent the point P, the computation should be evaluated from point A, which is outside the polygon boundary. The per-pixel instructions used to evaluate the PDM cannot be performed outside the polygon boundary E–F. The point P intersects at point C with the plane that is perpendicular to the surface E–F. Therefore, the overflow can be resolved by making the perpendicular plane and rendering information coincident with the texture coordinates of point P on pixel C. When point C is mapped to point A on the virtual extended surface E–D′ and the texture coordinate of point A is used, the point C on the perpen-

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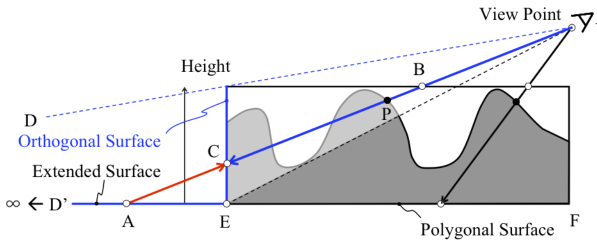
dicular plane can be represented using only one height map and a texture of original surface.

Fig. 2 (b) represents the extension of Fig. 2 (a) into three-dimensional space. The component ratio (vx, vy, vz) of the line segment A–V can be obtained from the coordinates of the viewing point in the tangent space. The uv space coordinates of point C on the perpendicular plane can be expressed by dx and dy. Using trigonometry, the uv space coordinates of point A, which is mapped to the virtual extension plane, can be derived as follows from the Fig. 2 (b):

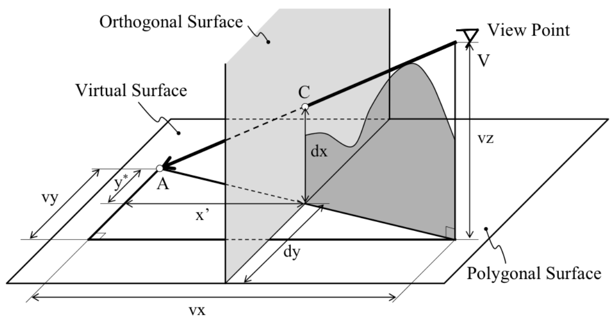
$$x' = \frac{(dx \times vx)}{vz}, \quad y' = \frac{(dx \times vy)}{vz} + dy$$

The tangent space coordinate of the perpendicular surface can be calculated using the relationship of the tangent space coordinate system between the polygonal surface and the adjacent surfaces. For example, the polygonal surface shown in Fig. 2 (b) has an orthogonal surface where the tangent space is transformed as follows:

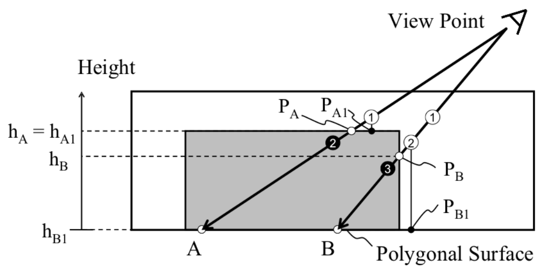
$$normal_{left} = -tangent, tangent_{left} = normal, binormal_{left} = binormal$$



(a)



(b)



(c)

Fig. 2. (a) Handling of pixel overflow, (b) Mapping of overflowing pixel, (c) Detection of steep surface of protruded object.

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A vertical surface is supplemented at the boundary where the overflow occurs according to the viewing direction. While rendering the supplemented vertical surfaces, only the protruded region of the object is selectively displayed using alpha blending. The result of representing the overflow region by adding faces that is perpendicular to the boundary of Fig. 1 (d) is shown in Fig. 1 (e). It shows complete silhouette at the boundary of the PDM.

4 Representation of a steep displacement

If a protruded shape with a steep slope is depicted with a box, it can be presented as Fig. 2 (c). Because the side of the box is perpendicular to the polygonal surface, a pixel in the texture coordinate fills the whole vertical edge in the side surface of the box. A steep slope is detected by the gradient of the protruding shape. For point P_A on a gentle slope, PDM finds the height value of point 1 in the uv coordinate by a linear search. Then, h_{A1} can be detected by the height value of point P_{A1}. The linear search stops at point 1 since the height value of point 2 is lower than the value from the height map. The precise intersecting point P_A is obtained by a binary search and its height h_A is almost the same to h_{A1}. On the contrary, for the case of point P_B on the steep slope, h_{B1}, the value from the height map until point 2 by the linear search, is located on the bottom surface. At this point, the height h_B of point P_B on the steep slope has significantly different value from h_{B1}. The point on the steep slope can be detected using this difference. Once the point is detected as a steep slope, we apply additional texture mapping using uv coordinates and the detected height value. For instance, texture coordinate of additional information for a steep slope can be calculated using following equations, where the $scale_x$ and $scale_y$ are scale factors for texture mapping in horizontal and vertical direction.

$$s = (u + v) \times scale_x + s_0, \quad t = h_B \times scale_y$$

5 Continuity of tangent space

When the PDM is performed on freeform surface, tangent continuity at boundary of each quadrilateral breaks due to the different height and different normal of terrain. It brings distortion of protruding shape. As this technique is originally desired for urban visualization, the entire protruding objects like buildings in urban representation are extruded exactly upward regardless of surface normal of base mesh. The normal of base mesh and tangent of the supplementary faces are amended to be parallel with geocentric normal. Consequently the continuityof tangent space transformed is secured.

6 Experiment

The PDM is implemented in a pixel shader using HLSL (High Level Shading Language) to test hardware acceleration capability and is applied to represent urban buildings. We used textures of 512×512 texels, and height maps

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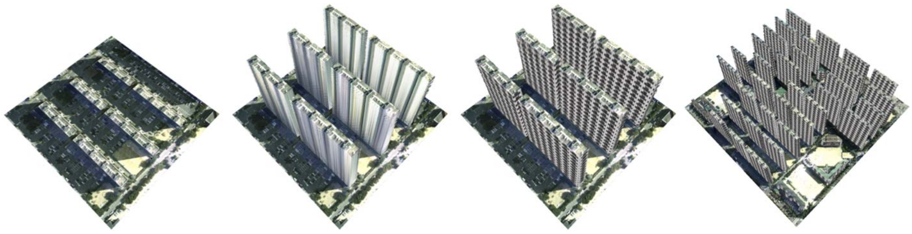

(a) (b) (c) (d)

Fig. 3. Protruded shape representation: (a) A quadrilateral with texture map, (b) PDM, (c) Wall texture applied with steep displacement mapping, (d) Multi-scaled application of the PDM.

composed of 256×256 RGBA texture. The building model in an urban environment is composed of 1024×1024 texels and 1024×1024 RGBA texture. In the experiments using a 2.8 GHz CPU with nVidia 7800GTX GPU, 250 fps for 10 steps of linear search and 70 fps for 50 steps of linear search were obtained for a 640×480 output image of PDM. 143 fps for 10 steps and 33 fps for 50 steps were derived from experiments for a 1024×768 output image. Consequently the PDM can be applied in real-time for general-purpose graphics applications.

Fig. 3 shows the results of the representation of urban buildings. Note that the proposed approach represents the correct silhouette around the building boundary with overflow handling as shown in Fig. 3 (b). Fig. 3 (c, d) shows more realistic buildings using the additional texture information with the steep displacement detection. A video clip explaining the proposed approach and experiments is available from http://goo.gl/xkYss.

7 Conclusions

The PDM for protruded shapes is proposed and implemented in programmable GPU. The proposed approach represents the exact silhouette along with the details of the protruded shape of an object. The increase in the number of polygon of the entire model is ignorable. It resolved the problem of the existing image-based displacement mapping methods, which represents only interpenetration into the polygonal surface and are unable to show the correct silhouette of an object.

As the PDM is particularly applicable to shapes protruding perpendicularly such as buildings, it can be utilized for modeling and representing real urban environments in location based services for mobile electronic devices with conventional graphics hardware based on a polygon model.

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