A Texture-Based Haptic Model Design with 3D Brush

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Abstract

We present a system for texture-based haptic model design with a haptic device. Texture mapping is an effective technique for texturing on virtual object surfaces at low cost and with high definition. We have proposed several texture-based haptic rendering techniques. In these techniques, the magnitude and/or direction of the reaction force is changed according to the texture image. As a result, our techniques enabled a haptic rendering at low cost and with high definition. In order to construct a texture-based haptic model, it is necessary to create a special texture of asperity, friction and stiffness. However, it is very difficult to create these textures themselves in general. Therefore, we developed a texture-based haptic modeling system now. This paper describes a technique to edit the texture seamlessly from the object surface with a 3D brush and a result of model designed using our system.

1. Introduction

In three-dimensional (3D) computer graphics, to construct a high definition virtual object with microasperity such as rock, soil, brick and cloth using geometric modeling, an enormous number of polygons is necessary and therefore requires substantial modeling and drawing costs. To reduce these costs, texture mapping is an effective technique and it can present a realistic appearance and texture by mapping the texture image such as rock, soil, brick and cloth onto the object surface at low polygon counts. In addition, it can present a haptic impression such as feeling of roughness of the rock, soil or brick according to the texture image by our texture-based haptic rendering technique [1]. In our texture-based haptic rendering, difference of haptic impression is presented by changing magnitude and/or direction of the reaction force according to the pixel value of the object surface which mapped the special texture image and converted asperity, stiffness and friction into the two-dimensional (2D) image. Unlike traditional haptic rendering techniques, it can achieve low cost and high definition haptic rendering with a small amount of data [2].

Figure 1. A dragon model designed by our texture-based haptic modeling system

To construct a texture-based haptic model, it is necessary to create a special texture which converts asperity, stiffness and friction into the 2D image. However, it is very difficult to create these various textures, and our previously developed systems could not create these textures intuitively and interactively. Therefore, we propose a texture-based haptic modeling system which enables user to create these textures intuitively and interactively in this paper .

A direct texture painting from the object surface is an effective technique to create the texture image intuitively. Moreover, it easy expect to construct a more realistic object intuitively and interactively by painting, texturing and haptic texturing on the object surface directly while feeling the haptic impression such as asperity, stiffness and friction according to the texture image. However, in texture mapping, each polygon of a 3D object in 3D space cannot develop in 2D texture space seamlessly [3]. Therefore, how to edit the 2D texture image seamlessly from the object surface in 3D space directly is the important problem to be solved. A projection-based painting [4] is a seamless painting technique, however it cannot paint on the object surface directly with a 3D input.

To solve these problems, we propose a technique for texture editing seamlessly from the object surface with a 3D brush. This paper describes a system for texture-based haptic model design and a result of model designed using our system in this paper.

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2. Related Work

2.1. Texture-Based Haptic Rendering

To present a high definition virtual object by haptic rendering, it is necessary to present a haptic impression such as asperity, friction and stiffness while controlling the haptic device at more than 300-1000 Hz update rate. Penalty-based haptic rendering [5, 6] which is one of the approaches to present the polygon wall, has several problems such as passing through, discontinuous force and vibration. To solve these problems, Zilles *et al.* [7] proposed a constraints-based God-object method. However, their method has the same problem such as passing through, discontinuous force and vibration in haptic rendering for the high polygon model. These problems are caused by discontinuity between polygons of a 3D object.

On the other hand, several texture-based haptic rendering techniques have proposed to represent the convexo concave of the interior of the polygon according to the 2D image. Stanney [8] proposed a force mapping technique which enable user to present the gradient of the object surface according to the normal map. In his approach, the direction of the reaction force is dynamically perturbed according to the pixel value of the interior of the polygon which mapped the force map. Theoktisto *et al.* [9] proposed a height field mapping technique which enables user to present the height of the object surface according to the height field map. In their approach, the surface height is dynamically changed according to the pixel value of the interior of the polygon which mapped the height field map. We proposed a high speed and high definition haptic rendering technique at low polygon model in previous work [2]. In our approach, the reaction force is calculated according to the pixel value of the object surface which mapped the special texture image and converted the geometric difference of the high polygon model and the low polygon model into the 2D image. Moreover, we developed a material system under haptic rendering for pseudo-roughness [1]. In our system, difference of haptic impression is presented by changing magnitude and/or direction of the reaction force dynamically according to the pixel value of the object surface which mapped the special texture image and converted asperity, stiffness and friction into the 2D image.

To construct a texture-based haptic model, it is necessary to create a special texture which converts asperity, stiffness and friction into the 2D image. A direct texture painting from the object surface with haptic device is an effective technique to create the texture image intuitively and interactively.

2.2. Texture Painting with 3D Haptic Device

Johnson *et al.* [10] proposed a texture painting system which paints directly onto trimmed NURBS models with a haptic device. Foskey *et al.* [11] proposed a 3D painting and modeling system which paints directly onto polygon models with a haptic device. Kim *et al.* [12] proposed a haptic decoration and material editing system which edits directly onto implicit models with a haptic device. We propose a system which enables coloring, texturing and haptic texturing onto the polygon model while feeling the haptic impression such as asperity, stiffness and friction according to the texture image in this paper.

3. Overview

3.1. System Architecture

Our system architecture is shown in Figure 2. Our system is composed of an application, a graphical display, and a haptic device. We use the Novint Falcon of 3DOF device for the haptic device. Novint Falcon is controlled via HDAL (Haptic Device Abstraction Layer) API.

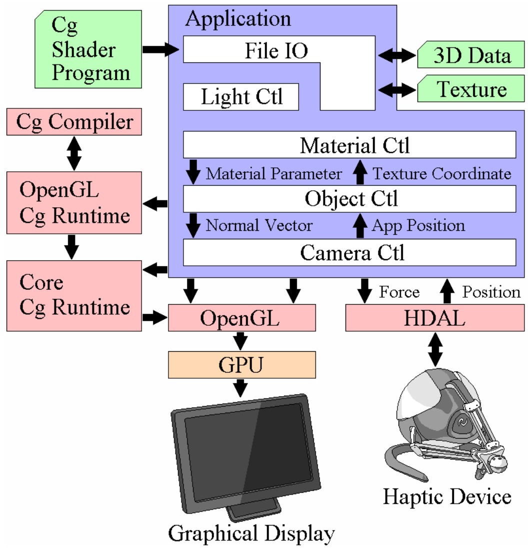
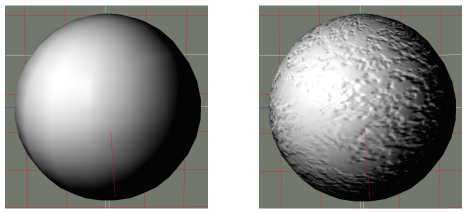


Figure 2. System architecture

In our system, a normal mapping technique [13] is used to represent asperity of the object surface (see Figure 3) and we used Cg (C for graphics) [14], OpenGL [15], and programmable GPU for per-fragment lighting.



(a) smooth (b) asperity

Figure 3. Normal mapping

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3.2. Geometric Modeling

In our system, geometric modeling is done by combining a polygon model, material and a texture map. The user can create a complex model by combining polygons freely (see Figure 4).

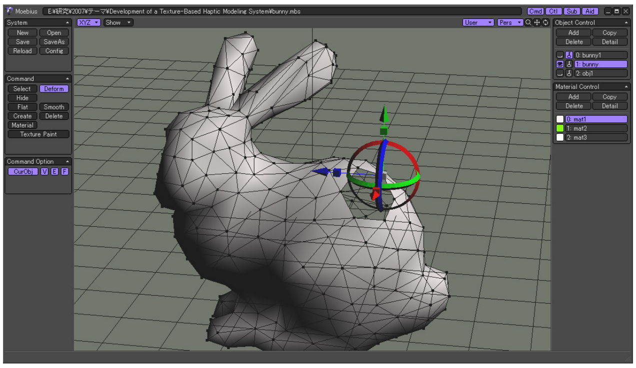


Figure 4. Geometric modeling

3.3. Material Editing

In our system, material parameters and texture map are set by a material editor (see Figure 5). The constructed materials are allocated in arbitrary polygons and the appearance texture and haptic texture are reflected as a result.

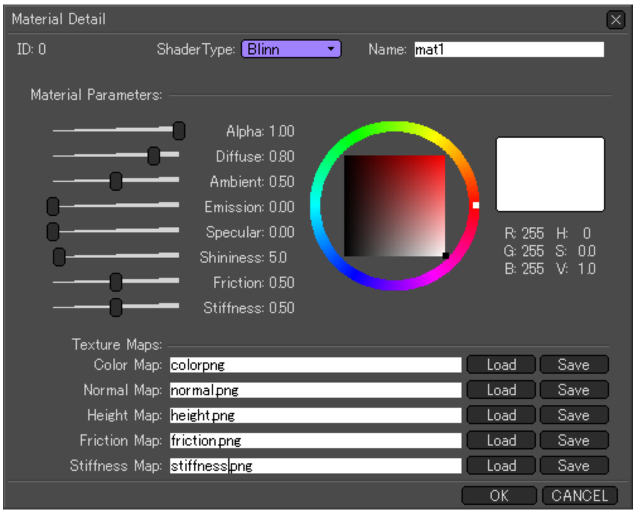


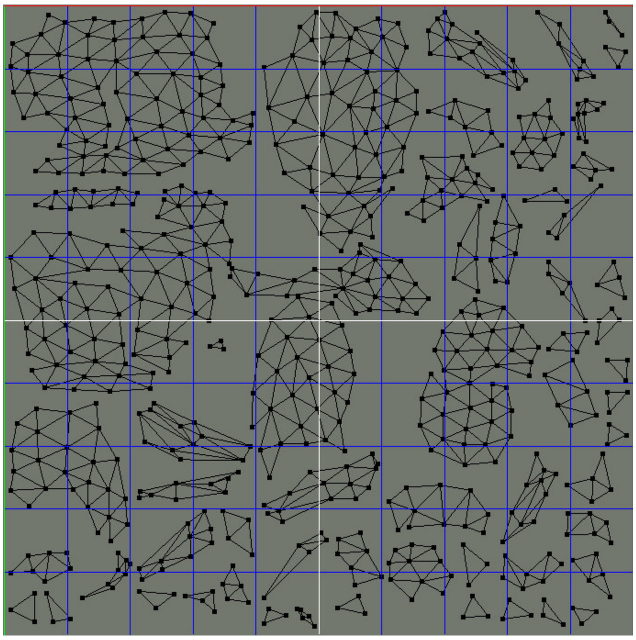
Figure 5. Material editing

The texture map of the initial color is generated automatically by entering an arbitrary file name into the edit box.

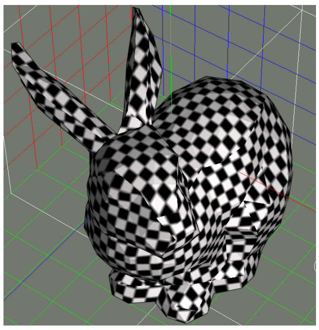
3.4. UV Mapping

Our system relates the 2D texture image to the 3D object surface by UV mapping. For eliminating distortion the mapped texture of the interior of the polygon, it is necessary to do the UV mapping in order to a uniform resolution. To control the distortion in our system, the user must adjust UV coordinates of each polygon in Figure 6a manually.

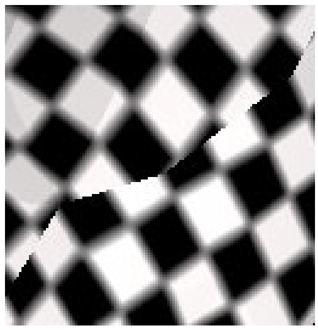
As an example, a UV mapped bunny model is shown in Figure 6b. In UV mapping, it is impossible to develop each polygon of a 3D object in 3D space into 2D texture space seamlessly. Therefore, seams of texture such as Figure 6c occur on the object surface in 3D space.



(a) UV map



(b) a UV mapped model



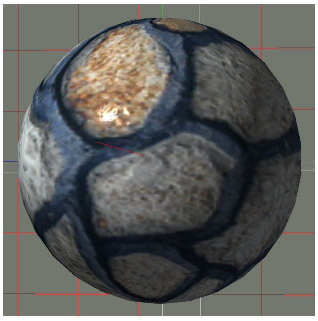
(c) texture seam

Figure 6. An example of UV mapping

3.5. Texture-Based Haptic Modeling

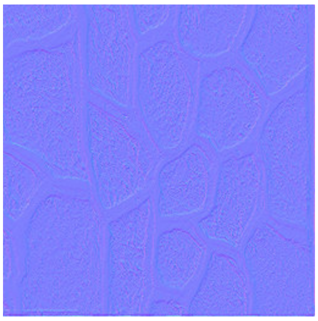
In our system, texture-based modeling is done by mapping various textures such as color map, normal map, height map, friction map and stiffness map.

As an example, a rock model is shown in Figure 7. The normal map is used to represent the surface gradient, where the RGB values correspond to the XYZ coordinates of the normal vector. The height map is used to represent the surface height, where the surface height is changed according to the grayscale value (white is high and black is low elevation) . The friction map is used to represent the surface friction (white is rough and black is smooth) and the stiffness map is used to represent the surface stiffness (white is hard and black is soft).

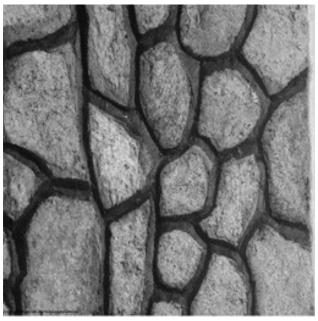


(a) a rock model

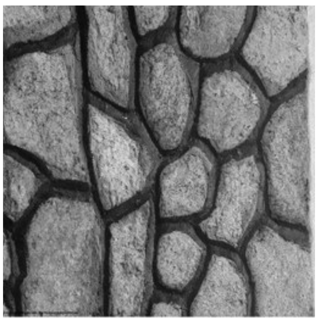
(b) color map



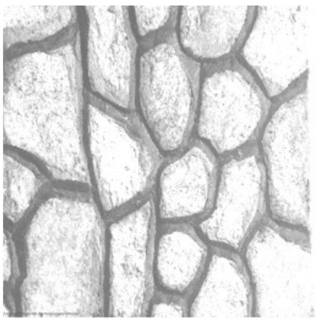
(c) normal map



(d) height map



(e) friction map

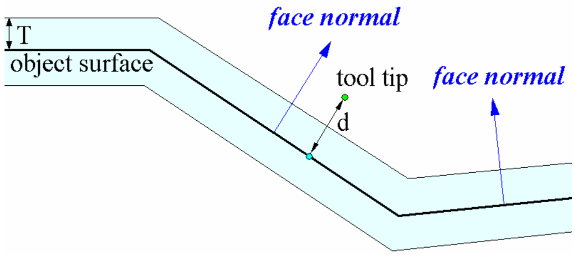


(f) stiffness map

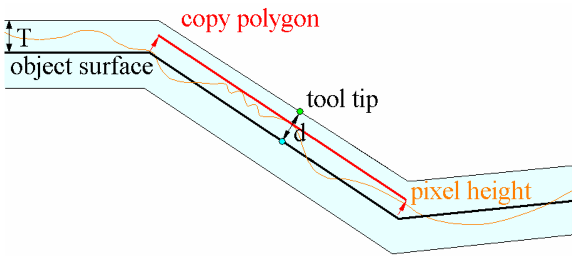
Figure 7. Texture-based haptic modeling

3.6. Texture-Based Haptic Rendering

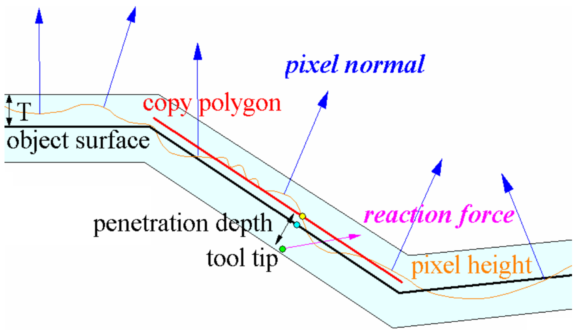
Our texture-based haptic rendering technique is shown in Figure 8. Our technique is an extension of the constraints-based God-object method [7].



(a) intersection detection



(b) copy polygon creation



(c) reaction force calculation

Figure 8. Texture-based haptic rendering

First, the intersection is detected between the tool tip and the object surface (see Figure 8a). We used Möller *et al.*'s method [16] for the intersection detection. Secondly, if they are crossed in the intersection detection and have the possibility of contact ($d \leq T$), the height of polygon is changed according to the pixel value of the height map in relation to intersection point and the polygon is replicated (see Figure 8b). Finally, the intersection is detected again between the tool tip and a copy polygon, and the reaction force is calculated according to penetration depth and the pixel value of the friction map, stiffness map and normal map (see Figure 8c).

4. Seamless Painting with 3D Brush

In this section we describe a seamless painting technique with a 3D brush.

4.1. Texel Transformation

To solve the problem at texture seams in Figure 6c, our system converts each texel in 2D texture space into the 3D vertices of the 3D object surface in 3D space. We attempt to solve the texture seam problem by use of painting from these 3D vertices.

First, the intersection is detected to each polygon in UV space of Figure 6a with the form of raster scan. If the intersection is observed, an intersection point of the interior of a polygon in UV space is converted to 3D coordinates on a polygon of the 3D object in 3D space.

Each texel converted into 3D vertices is shown in Figure 9. Each 3D vertices corresponds to texel coordinates. This process makes it possible to edit the texture seamlessly with a 3D brush.

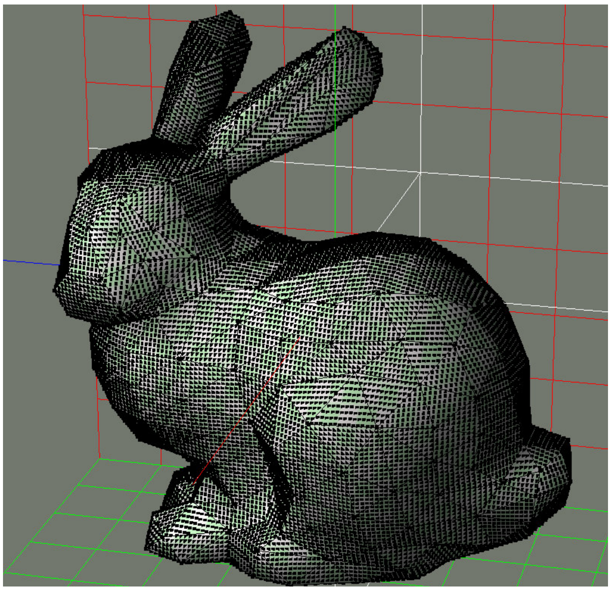
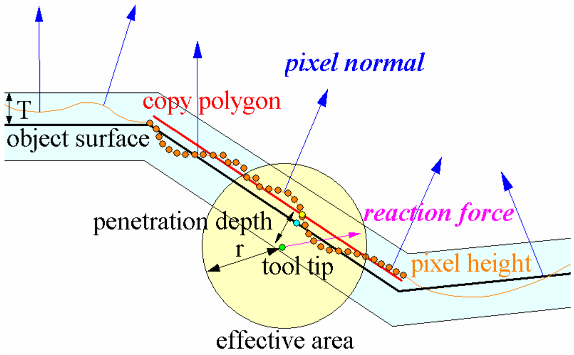


Figure 9. Texel transformation

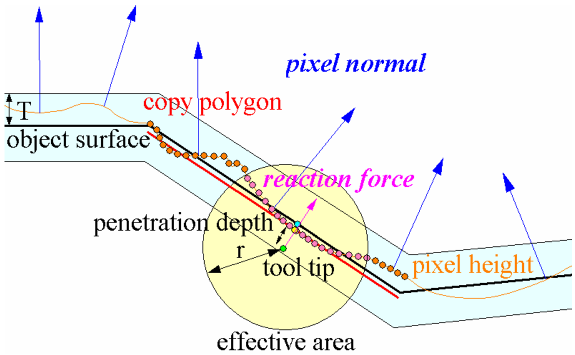
4.2. Texture-based haptic painting

The haptic rendering at 1000 Hz update rate and the texture editing at 60 Hz update rate are adopted in our system to edit the texture while haptic rendering.

First, a target polygon for the texture editing is obtained from a brush size r when a button of a haptic device is pushed while haptic rendering (see Figure 10a). Secondly, a pixel value of various textures in relation to the 3D vertices within an effective area of a 3D brush is renewed at 60 Hz update rate. At the same time, the reaction force is recalculated according to the renewed various textures (see Figure 10b).



(a) target acquisition



(b) texture editing

Figure 10. Texture-based haptic painting

5. Results

Color painting result at the texture seam is shown in Figure 11, and output result of a color map is shown in Figure 12. The texture size is 256×256 pixels and a circle brush is used for color painting.

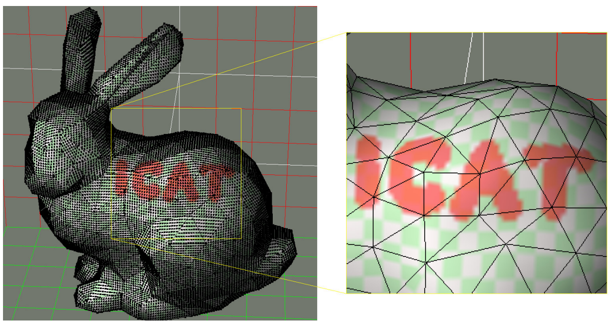


Figure 11. Color painting result

Our technique enabled seamless texture painting at the texture seam.

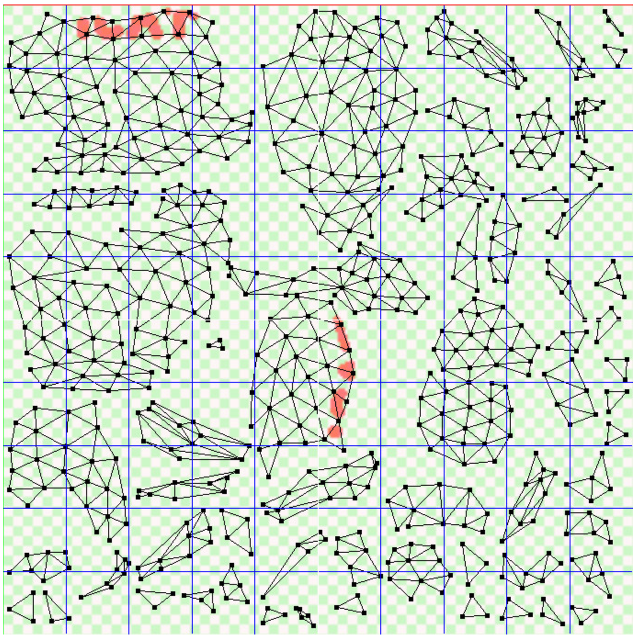


Figure 12. Output result of a color map

A model result designed using our system is shown in Figure 1. Our system enabled texture-based haptic modeling interactively with a 3D brush by using haptic device.

6. Conclusion and Future Work

We presented a system for texture-based haptic model design with a haptic device. This paper described a technique to edit the texture seamlessly from the object surface with a 3D brush and a result of model designed using our system. Our system enabled texture-based haptic modeling interactively by painting, texturing and haptic texturing on the object surface directly while feeling the haptic impression such as asperity, stiffness and friction according to the texture image.

However, our system currently does not deal with automatic control of the distortion of the texture. Therefore, the user must adjust UV coordinates of each polygon manually. In the future, we plan to extend the current system by implementing the function of the texture editing with various brush shapes and the control of distortion of the texture automatically.

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