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A New Approach for the Synthesis of Glistening Effect in Deformable Anatomical Objects Displayed with Haptic Feedback

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Abstract. An environment mapping approach for texture mapping of anatomical objects with glistening was studied and implemented in surgical simulation. A classifier based on the generalized goal of achieving glistening effect, which depends on the underlying physics and the mapped data, was used as a visual metric and shown to be realistic in the presence of achieving the desired quality in real time in the presence of haptic feedback. The proposed approach was compared with the standard texture mapping approaches used in existing surgical simulation methods that generally suffer from texture stretching and with little or no glistening effect. In our work, we have successfully applied environment mapping techniques for realistic real-time rendering of anatomical objects. We also show several examples of anatomical objects with glistening effects that mimic real anatomical objects.

1. Introduction

The problem of texture mapping [1], where texture parameters are not explicitly given or when the underlying geometry is non-planar and non-rectilinear, but rather available as complex shapes that occur in anatomical objects, is of considerable importance in virtual surgery simulation [2,3] and in a variety of 3D graphics applications [4,5,6,7]. Unfortunately, all the previous work on texture mapping approaches for 3D complex surfaces focus on solving the texture stretching problem place very little emphasis on photorealism with glistening effects. The only exceptions are images produced for visual effects in movies that are not done in real time. The need for perceptually based rendering procedures that produce synthetic images that are visually indistinguishable from real-world environments has been emphasized in recent years. Realistic rendering has been a challenge when it comes to representation of non-geometric structures. Visual realism is essential to make the simulation life-like and that is the goal of our work described here.

The problem we addresses is the following: given one or more arbitrary meshed and their associated RGB texture to render them in real time, with glistening effects similar to that obtained using expensive ray casting. The grid can deform at the same time as well. Some of the issues are listed below.

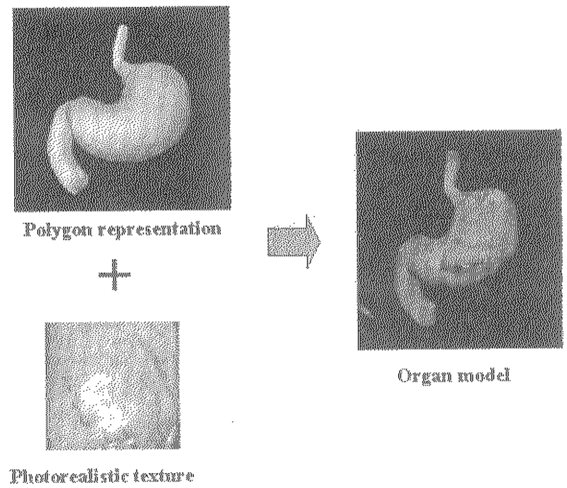

Figure 1 The process of texture mapping on a polygonal organ model

Multiple objects: The problem we model here is for surgery simulation with multiple anatomical organs. Each object has a large number of polygons and in most cases is a topologically closed object. The performance issue here arises especially when the rendering context switches between the different objects in the scene. Our goal is to have smooth models and more than one of such objects in the scene.

Multiple textures: Each organ model can have one or more textures associated with it. Multiple textures are required especially when constructing a two-sided surface where the textures on both sides of the mesh may be different. In the case of environment mapping we present, multiple textures may be needed for one object. The goal here is to ensure that multiple textures should be supported.

Deformable objects: One good example of a deformation is palpation where a surgeon needs to examine the organs by poking via probes. The deformation of the organ models leads to the update of vertex positions and polygon orientations that need to be computed for rendering. Since real time display of deformations is essential in surgical simulation, the texture mapping technique should be capable of displaying the deformation of the underlying surfaces.

Force feedback: Force feedback or haptic feedback is necessary in surgical simulation to improve realism of the simulator. When the force feedback is involved in the system in addition to visual display of deformation, high update rate (at least a few hundreds of Hz) is required to provide realistic feeling to the users in real time. It imposes an additional constraint to generate a response/feedback to the users.

Glistening effect: The smooth glistening appearance of the internal organs is partly due to the lining by the serous membrane (serosa). The complexity associated with modeling multi-layered thin films and the physical behavior of light by explicitly tracing the light rays throughout a scene has led to the exploration of alternative techniques to simulate realistic reflections. Since the simulation of glistening effects by conventional ray casting requires considerable computational effort, it is difficult to simulate such effects at interactive rates.

2. Texture Map for Anatomy

2.1Texture Mapping for Range Images

One possible approach for texture mapping is to extend the techniques used for 3D digitization. In the approach proposed by Lee [4], the texture construction for facial texture mapping, two images are accomplished by assembly from the front and side views. A cylindrical projection of each image is obtained. The projected images are cropped at the eye extremes vertically. A multi-resolution assembling is performed to ensure smooth boundaries. The problem of texture fitting is to identify texture points for all points on the anatomical object. Texture coordinates of feature points are obtained from position data and a function applied for texture image generation. A cylindrical projection is applied to every point on the head surface. Extra points are added to obtain a convex hull containing all the points, so that coordinate of every point is located on an image. Then a Voronoi triangulation on control points and extra points are processed and the local Barycentric coordinates of every point with a surrounding Voronoi triangles are calculated [8]. The texture coordinates of each point on a 2D texture image are obtained using the texture coordinates of control points, extra points and the corresponding Barycentric coordinate [9]. This method has been successfully applied for facial models and the results are impressive, except that it takes few minutes to texture map each frame and hence not suitable for our work [10].

2.2 Tiled Texture Mapping

Another possible approach for texture mapping of anatomical objects is the so-called Tiled texture maps. Texture mapping of general non-rectilinear surfaces synthesize textures on the surface itself. There are several research efforts that map textures on manifolds (polyhedron) from tiled texture images. Delinguette [11] uses a tiled texture mapping technique to display a liver model. The our lab has presented results that use a simple texture mapping supported by Open Inventor from TGS for the bile duct exploration simulation [12]. Although they show a certain degree of realistic appearance of anatomy models, they suffer from the texture-stretching problem, which is an undesirable feature, and in addition have no glistening effect.

2.3 Other Possible Approaches

A simpler approach would be to have an oriented projective texture map where we project the surface texture onto scaled projection coordinates of the texture map available on orthogonal planes. The projected location and its texture or function of the texture is used to obtain the pixel texture. An alternate but fast solution is to use environment maps used in our research. The properties of environment maps and the algorithms are described in the next section.

3. Environment Mapping

Environment mapping technique is an efficient technique to compute the reflection vectors without adding real time computations. Although this technique was developed around the 1970s [13], this became available in PC level workstations recently due to the advance of computer graphics hardware.

In general, human beings perceive the properties of surfaces by the degree to which light is absorbed and reflected. To simulate this fully, the complicated modeling of light is required to specify the direction of secondary rays from the surfaces. In real time applications, it imposes extra computational burden on system, which have limited computing capacity. Therefore, some realistic effects requiring this computation, for example a glistening effect, are difficult to be simulated in real time surgical simulation due computational burden on the system. The environment mapping approach uses a simple form of reflection-vector dependent texturing and pseudo ray tracing computations. In other words, by projecting 3D environments surrounding the object onto a 2D environment map, reflections can be approximated with some degree of accuracy and significantly reduced real time computations.

3.1 Environment Map Design Issues for Anatomical Objects

For practical environment mapping the following processes are involved:

- Texture comes from encoded images of the environment in all directions and its converted images depend on mapping methods. In case of cube mapping, the images are mapped onto cubes, while the images are mapped onto spheres in sphere mapping
- Reflection vectors are precomputed and mapped to texture coordinates to reduce real time computations in the simulation

Environment mapping technique has several advantages over traditional texture mapping techniques for surgical simulation. First, the connectivity on a projected texture is maintained, because normal vectors change smoothly from one texture to another. Second, it is not necessary to flatten the entire surface of the anatomical object. Just one triangle is flattened at a time. So we don't need to worry about flattening neighborhoods. Finally, topology of the model is maintained, because a triangle can be projected always to one of the cube faces. The local texture orientation is implicitly maintained, so that no uneven scaling or stretching occurs as in traditional texture mapping techniques.

However, in spite of the computational speed and quality of the mapping, there are several limitations to environment mapping, such as no self-reflection properties. Therefore, careful consideration for obtaining and implementing are required to apply it in surgical simulation.

3.2 Anatomical Environment Map Algorithm

This section describes the procedure used for the construction and rendering of the anatomical objects. We used OpenGL v1.2 to implement this technique in a WinNT based computer.

Anatomical Environment Map Algorithm
OpenGL Environment Map Setup Usage
Step 1. Binding to a environment map texture
Step 2. Loading environment map textures
OpenGL Environment Map Rendering Usage
Step 1. Enabling an environment map texture

```
        glEnable(GL_TEXTURE_ENV_MAP);
Step. 2. Generated environment map coordinates (explicit or implicit)
        glTexCoord3f(vx, vy, vz); // (vx,vy,vz) is unnormalized direction
    vector
Step. 3. Generate anatomical object with textures
```

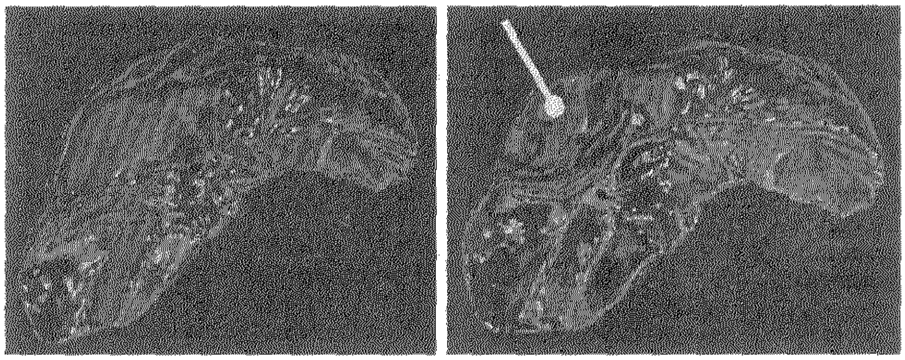

Figure 2. Glistening liver rendered using a Cube map (left panel) and Glistening liver deformed and rendered using a Sphere map (right panel)

4. Discussion

Experiments were performed to test the environment map for anatomical objects with glistening effects. In our experiments, we assumed that the textures are loaded during the initialization of the program. The texture images are captured from the laparoscopic video images of a real medical procedure. In the current graphics hardware, two kinds of environment mapping techniques are available depending on the shape of a map: sphere mapping and cube mapping. The sphere mapping is less computationally expensive, but has view point dependency such as warping or distortion.

4.1 Experiment One-Cube map

This experiment was designed to test cube maps for different anatomical objects. The emphasis here was to generate a glistening effect. Fig. 2 left panel shows the rendering with glistening effects for a deformed model. The rendered image has the following properties. First, the rendered image shows the glistening effect that was the original goal. Second, the rendering can be done in real time. Third, the results produced are far superior to the results reported in the literature.

4.2 Experiment Two – Sphere Map

This experiment was designed to test the glistening effects obtained from sphere maps instead of cube maps. The sphere map instead of a cube map uses the reflection over the sphere and uses a single texture. Although it requires less memory and computation, the image is a little bit distorted. Fig. 2 right panel. shows the rendering of the deformed liver, which is another major goal of this research. The anatomical models have to be deformed as well. In the ideal situation the deformation has to be done in real-time.

4.3 Experiment Three – Performance Evaluation for Environment map

This section describes the performance evaluation obtained through analyses, simulation and some timing measurements. Table 1 summarizes these results. We used GEForce 2 from NVIDIA, which provides hardware-supported environment mapping features and E&S Tornado 3000 from E&S, which has only software emulated environment mapping techniques. From table 1, we observe that the cube mapping and sphere mapping using GEForce 2 shows better performance in rendering organ models with glistening effects. If we simulated the same effect by using conventional texture mapping techniques, it is very difficult to achieve real time performance due to the huge amount of computations required for ray tracing. We also observe that the software emulated environment mapping technique is not recommendable for rendering of complicated anatomy objects due to its poor performance as shown in Table 1. The graphics cards with hardware support of environment mapping are three times faster than graphics cards which do not support an environmental mapping technique in the simulation of complicated effects.

Table 1 Rendering Performance of Environmental Mapping

Object	Grid Size	Rendering capacity per second		
		Cube Map (GeForce2) MTriangles/sec	Sphere Map (GeForce2) MTriangles/sec	Sphere Map (E&S Tornado 3000) MTriangles/sec
Liver	17536	1.714	1.121	0.387
Stomach	51264	1.645	1.477	0.377
Lung	27648	1.714	1.593	0.388
Kidney	16512	1.710	1.408	0.371
Intestine	68456	1.581	1.656	0.412

5. Conclusion

We have analyzed and described the results of the use of environment mapping for deformable organ models. The novel aspect of the results presented here is that glistening effects of organ models can be achieved in real time. The quality of the effect is comparable to ray tracing. Such a technique has not been reported before in literature. The significance of the results is that deformation with glistening effect can be displayed in real time together with force feedback. Such an effect has a significant impact on the realism that can be achieved in interacting with virtual environments for surgical simulation.

6. Acknowledgments

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