Realistic Shading of Human Skin in Real time

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ABSTRACT

The demand for realistic human characters is driven by interactive application developers worldwide. The look of 3D models in real time graphics is efficiently improved by powerful shader techniques. Today a common technique consists of a simple lighting model combined with textures, which have pre-calculated illumination included. In this paper we will give an overview of the most recent techniques in skin shading. We present a multifaceted implementation of shading techniques by efficiently combining various approaches. Therefore we will explain physical and anatomical backgrounds and refer to relevant papers. In our opinion, this work is a valuable reference to assist shader developers in their implementations and adaptions on recent and future graphic hardware.

Categories and subject descriptors:

I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism - *color, shading, shadowing, and texture*;
J.7 [**Computer Applications**]: Computers in other systems – *Real time*;

Additional Key Words and Phrases:

Rendering, Lighting, Interactive Application Development, Visualization and Simulation, Human, Skin

1 INTRODUCTION

An authentic appearance of virtual humans is becoming increasingly significant in a variety of applications. Computer games or virtual agents should provide a consistent world and credible characters. Since the viewer is familiar with the appearance of humans it is difficult to create realistic artificial characters. This simulation has to be close to perfection to convince an observer. The complex topology of the human head, the manifold layers of the skin and their behaviours when interacting with light are challenging simulation tasks.

The human skin is built of different layers each with its own characteristics and functions. There are three basic layers with the epidermis as the outermost layer. Its thickness and color depend partially on the skins physical interaction during daily usage (i.e. becoming cornea if intensely stressed). At the cheekbones or eyelids the skin is thinner, whereas being thicker and more yellow around the lips. Thinner parts seem more reddish due to the small blood vessels of the next deeper layer of the skin – the dermis. The hypodermis contains the collagen and fat depots which define the consistency and flexibility of the skin. Numerous natural pores whose amassment varies over the surface are part of the skin. Some of them protect the skin from running dry and diseases by producing a fat like fluid. Other pores produce sweat to cool down the body.

Apart from the structure there are other superior attributes like nationality and gender, which lead to overall variations. The different layers of the skin change in the process of aging. The hypodermis looses its capability of storing fat. Thus the connective tissue looses its strength, and the skin becomes dry. It gets less smooth and is wrinkled. The epidermis becomes thinner and appears like parchment. [Trebsdorf 1993]

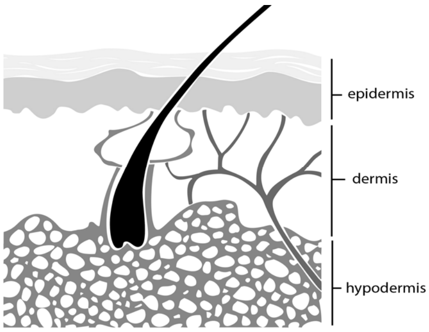

Figure 1: Layers of the skin

The techniques described in this paper can be used to improve the appearance of virtual humans. Our methods are scalable and extendable to various requirements for advanced realism. The combination of the base geometry with fine details provided by normal maps will be illustrated. Moreover diffuse attributes, reflections on top and inside the layers of the skin are discussed in this paper. Such as the sequence of rendering passes and texture space lighting. This paper resulted from the project "Artificial Actors" at the Institute of Animation, a part of the Filmakademie Baden-Wuerttemberg. More information and supplemental material to this paper can be found at *research.animationsinstitut.de*.

2 GEOMETRIC DETAIL

The appearance of a credible human skin depends on the underlying topology. Starting with the basic shape of the head and ending at fine details as folds and pores. An eligible construction is important for efficiency, animation, and realism to represent a character.

The base is a polygonal model. Our model of the human includes shape and distinctive furrows. For efficient geometry based animation the head model with 3.500 vertices represented fast interactive display rates. Langer's Lines were considered which indicate the figure of wrinkles. The model contains permanent visible wrinkles such as a frown. Also folds which are only seen when some facial-expressions are formed. In the following different approaches to provide additional detail to the base geometry are discussed.

Detail normal mapping is a technique to achieve higher geometric detail [ATI 2003]. A detail normal map is generated by comparing the low polygonal model with a high detailed one. Based on this map new normals for the lighting calculations are constructed. The resulting object has a smoothed angular geometry, refined folds and further details.

For smaller characteristical traits as the dermis' small fielded structure we used bump mapping [Blinn 1978]. This map can be generated from a grey scaled height map. For faster handling this two maps are combined in one normal map. The normal mapping technique presented by Blinn et al. or further approaches like parallax normal mapping [Welsh 2004] can be used to create the new normals. To reduce effort and increase efficiency, details can be shifted from the base geometry to the normal or bump map.

Figure 2: Wireframe, normal mapped and additionally bump mapped

3 BASIC SKIN

Shading techniques provide the needed flexibility for dynamic characters in complex light situations. This chapter describes methods of skin shading accomplished with diffuse illumination.

3.1 Fundamental Maps

The color map for itself is suggestively separated from the illumination. It keeps the variety of the skin's color without any kind of self-shadowing. It is created in coherence with the normal and bump map in using photographs as reference.

Blemishes like birthmarks, furrows, freckles, pimples, aging flecks and the typical grainy pattern of pores all have a slightly varying appearance, intensifying the skin's uniqueness. Thick, dense callosity parts of the skin are more yellow and thinner parts more reddish. Other examples are arteries that appear bluish, and bones underneath the narrowed skin seeming whitish. Furthermore exertion raises the blood circulation changing the color of the skin partially into more red, whereas for example a squeezed hand will be whitish. In providing enough fine detail, the observer will receive enough visual information so that he can be distracted from the fact that a character might be a virtual one.

Diffusion determines the relation of uniformly reflected and absorbed light by a roughness factor. This behavior varies over the skin's surface. Captured by a diffuse map it can be utilized for the diffuse lighting. Roughness is less on dryer parts, thicker or for example on hardened cornea parts. Reflecting less diffuse light and appearing to be softer. In chapter 3.2 extensions to the harsh lambertian lighting model are discussed to fit the soft skin.

3.2 Illuminating Skin

Illumination is an enormous issue in computer graphics giving single colored objects a complex shade. The Phong/Blinn model was preferred in real time graphics for years. Compared to the far more advanced models of offline rendering it is fast and easy customizable.

Illumination of skin can be decomposed into single surface components of shadowed skin, lit skin, and transitions between these two. Each component is physically complex but can be divided into several subcomponents. To control contrast, saturation, transitions etc. we used a color gradient. Indoor lighting and for example classical three-point lighting [Birn 2000] have saturated transitions and low contrasted shadow colors. Figure 3 shows a gradient and the result combined with a color map. Outdoors light rays seem to fall in from all directions. The overall gradient is softer and shadows are less strong. The use of the gradient allows controlling many different light situations with the use of the Phong/Blinn model.

Figure 3: Color map, use of the color gradient and result

Small details in diffuse lighting have a more or less subconsciously perceived influence on the skin's softness. Details are reduced in shadowed areas and enlarged in specular parts as mentioned in chapter 4. This results from reflections at all angles from rough surfaces known as backscattering. The surface is brightened at the edges resulting in a smoother appearance. Therefore the influence of the normal/bump map should be reduced if the diffuse luminance value is small. The Oren-Nayar reflection model [1994] accounts for the backscattering effect and might be used as well.

To simulate the effect of less detail a second normal map can be used for interpolation by the luminance. The second map has less detail. Equation 1 illustrates this effect for normal maps. The normal from the original normal map is interpolated with the less detailed normal from the second map by using the luminance. This normal can be used with the already mentioned techniques. In the same manner a second saturated color map can be used. This will lead to a more saturated reddish color in darker areas.

$$normal = luminance \cdot orginalNormal + (1 - luminance) \cdot blurredNormal$$

$$\begin{aligned} normal &: \ new\ surface\ normal \\ luminance &: \ surface\ luminance \\ orginalNormal &: \ orginal\ surface\ normal\ from\ first\ map \\ blurredNormal &: \ blurred\ normal\ from\ second\ map \end{aligned}$$

Equation 1: Backscattering effect

Apart from single light sources, a cubic environment lighting model can be used [Dietrich 2002]. The cube map contains blurred images of the environment - representing the luminance of the entering color. The colors from the cube map can be changed in contrast, saturation etc. to get similar effects as with the color gradient. The normal modulated by the normal/bump map is used for looking up at the diffuse lighting cube map. Cubic environment mapping allows reproducing complex light situations. An example can be seen in figure 4.

Figure 4: Diffuse lighting cube map, cube lighted character and an occlusion map

3.3 Ambient Occlusion and Shadows

Illumination is crucial to indicate the dimension of an object and the fine details of its shape. Shadows are very important in making a computer generated image more realistic. Different approaches can be used to calculate shadows from global illumination data like the positions of light sources and the shape of an object. Shadow maps [Ahokas 2002] or volume shadows [Atherton et al. 1978] are often used in interactive applications. In our example, we have a few objects in a scene all close to the viewer. In this constellation shadow maps work well. Advancements like perspective shadow maps [Stamminger and Drettakis 2002] might provide better results.

In most cases not all areas are accounted by shadows. E.g. the light does not reach to the inner bottom of wrinkles. An ambient occlusion map depicts areas that light hardly obtains. In a similar manner as radiosity [Neumann 1995] such maps can be pre-calculated in testing the amount of light that reaches each surface point. Light from different light sources and reduction of brightness by outreaching geometry are accounted.

4 SPECULAR REFLECTION

Specular highlights directly reflect light sources and in more advanced lighting models also light bounced off from surrounding objects. Reflections at the skin's surface depend on the viewing angle, density, oiliness and wetness.

The pores of the epidermis emit a natural fat like fluid to protect the skin. Depending on density and quantity of pores this emanation varies. Firmer skin secretes less fat, so reflections are less bright. Whereas around the eyes, especially at the eyelids highlights are stronger. This base specular can be instructed by an oiliness map. The skin's oiliness has only a subtle influence on the color inflicting a soft blue/white. The oiliness of elderly people's skin appears far less due to the retrieving fat cells.

If a character is physically active sweat glands produce perspiration. Shininess increases and beads of sweat may be formed. A noise map with fluctuations all over can be used to control this perspiration driven by the character's sweat factor. The formed overall figure should have a high contrast to simulate sparkling beads of sweat. Reflections can be simulated by a cube map using the reflection vector of the light as lookup vector. The cube map contains the blurred environment with a lowered contrast. The colors should use a flat spectrum with relatively small values. Figure 5 is achieved by using a dynamic cube map, rendered from the characters environment.

Details on skin are foremost seen in bright areas. This helps to increase the appearance of soft skin. Details reflect the light in different directions according to the normal/bump map whose influence should even be stronger in highlighted areas.

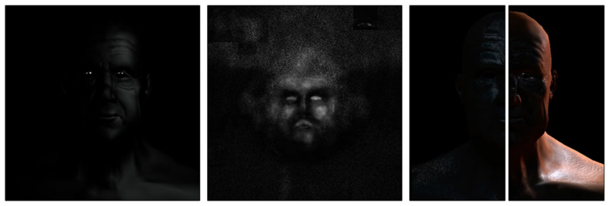

Figure 5: Specular layer, perspiration map, perspiration layer and result

5 SUBSURFACE SCATTERING AND TRANSLUCENCY

There are several techniques that simulate the subsurface scattering phenomena. In most cases they have one thing in common – they are numerically too complex for interactive environments. Our work presents an efficient approximation.

5.1 Subsurface Scattering

Subsurface scattering is the effect of light that is reflected inside and between the different layers of the human skin. Light rays might leave the skin at a different position and at a specific angle determined by the light's way through the skin. This effect is important in order to create a realistic appearance of skin. The BSSRDF model [Jensen et al. 2001] was developed to simulate this phenomenon. Due to efficiency issues in real time graphics we based our approach on an approximation from [Campin 2003]. We already explained some aspects to intensify the effect of subsurface scattering. Such as detail and color variations to soften the skin. Additionally strong subsurface scattered areas appear in a reddish hue and blurred. Less scattered areas in soft blue nuances.

In principle Campin's approximation has two values to control the behaviour of the softness. *softnessMin, softnessMax* regard the color gradient, upper and also lower transition areas. The values range from -5 to 5 and should be balanced to get a suitable contrast. We simplified Campin's approach to fit the instruction limit of the pixel shader profile. Therefore only small adjustments to *softnessMin* and *softnessMax* have to be done. With the *facingRatio* faces are brightened the more perpendicular their normal points to the viewer. This value produces a good contrast between the character and the edges. The already calculated diffuse luminance forces illuminated parts to be stronger subsurface scattered.

$$facingRatio = (1 - (normal \bullet viewDirection))$$

$$sssFactor = \frac{facingRatio \cdot (luminance - softnessMin)}{softnessMax - softnessMin}$$

$facingRatio$:	alignement from face to viewer
$normal$:	vector, surface normal
$viewDirection$:	vector, vertex to viewer
$sssFactor$:	strength of subsurface scattering
$luminance$:	diffuse luminance
$softnessMin, softnessMax$:	softness parameters

Equation 2: Subsurface Scattering Factor

To simulate the mentioned effects we used a similar color ramp as in figure 3. The horizontal-lookup value for this ramp is given by the *sssFactor*. The resulting color is added to the prior color and reddens the skin in these specific parts. As improvement a black and white ramp can be utilized instead of the color ramp. This resulting factor is multiplied with a subsurface scattering color map. This map may include variations like bones and veins seen through the skin or contains less affected regions.

Figure 6: Without subsurface scattering, subsurface scattering layer and result

5.2 Translucency for Ears and Nose

Translucency describes the effect of an object's transparency without being fully transparent. Just silhouettes from items behind the translucent object are formed by light and shadows which shines through.

This behaviour has to be considered for the ears and nose to give them a reddish look if lit from behind. Two transparency maps were used to decide which areas will be affected. One map masks thinner parts around the ear and the other frontal areas around the nose. As scaling factor a dot product between the orientation vector of our character and the observer's viewing direction is calculated. It determines the influence of the nose and ear mask shown in equation 3.

$$translucencyMap = (1 - abs(objectOrientation \bullet viewDirection)) * earMap + abs(objectOrientation \bullet viewDirection) * noseMap$$

$translucencyMap$:	potentially translucent parts
$objectOrientation$:	vector, watch direction of character
$viewDirection$:	vector, vertex to viewer
$earMap, noseMap$:	alpha map for ears and nose

Equation 3: Translucency Map

Equation 3 masks the parts that are potentially translucent. The next step is to check whether there is light directly behind the character. For point light sources the dot product of the *viewDirection* and the light vector results in a value close to -1 if the angle between both vectors is near to 180°. With concave surfaces equation 4 causes problems.

$$translucency = \min(0, (viewDirection \bullet lightDirection)) * translucencyMap$$

$translucency$:	translucency factor
$viewDirection$:	vector, vertex to viewer
$lightDirection$:	vector, vertex to light source
$translucencyMap$:	potentially translucent parts

Equation 4: Translucency Factor

The result matches translucent parts. In multiplying the *translucency* with the subsurface scattering color map the final result shown in Figure 6 is achieved. For cubic environment lighting the negative *viewDirection* can be used as lookup vector to calculate the *translucency*.

5.3 Additional Improvements

Rim lighting provides a nice glow around the edges of our character and intensifies the impression of backlighting. The light seems to shine through the skin at the edges. The calculation is described in Equation 2 as *facingRatio* and should be multiplied with a bluish color.

Most of the diffuse color of the skin is generated by subsurface scattering [Gosselin 2004]. Mentioned by [Jensen 2003] subsurface scattering smoothes or blurs the skin which can be approximated in texture space. This is discussed in chapter 6.

There are lots of techniques that are going to approximate the subsurface scattering effect in a more simulative way. Translucent Shadow Maps [Dachsbacher and Stamminger 2003] and the subsurface scattering approach from [Hanrahan and Krueger 1993] are examples that might be appropriate for future constellations.

6 RENDERING PROCESS

The described techniques can be realized in a single rendering pass. Further improvements can be achieved by using additional passes for post-processing. In principle two types are advisable.

The already rendered image can be used to do post-processing. E.g. for a depth-of-field effect. Based on the *translucency* factor from equation 4 these parts of the rendering are blurred during post-processing. Therefore the alpha value of the first pass is used to transfer this factor.

Texture space lighting described by [Borshukow and Lewis 2003] allows the realization of this effect in an even more meaningful way. [Gosselin 2004] uses this approach to render the diffuse lighting into a texture for filtering. Blurring the diffuse lighted texture removes harsh edges like those that are typically found when using the lambertian model. In another pass the specular light is added and finally a sizable filter kernel is used to simulate subsurface scattering with a spatially varying blur indicated by a mask. The alpha value is created from the values of *sssFactor* and *translucency*. The higher the masking values are the larger is the size of the filter, respectively the distance of the samples from the pixel.

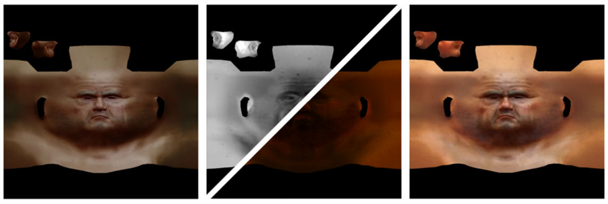

Figure 7: Final diffuse and specular lighting, subsurface scattering mask, final in texture space

The resolution of the texture is adjustable to the object's size on screen. But it can be rather slow due to the need of multiple rendering passes. The quality depends on the texture size. Some unnecessary calculations are done when lighting the entire object. Depending on the UV-mapping and the mesh's structure some visual artefacts may be visible.

7 RESULTS AND CONCLUSION

We tested several configurations of texture maps and shader techniques. Our final character shows clearly the effective implementation of the above mentioned techniques in real time. With an ATI Radeon 9800 XT we achieved frame rates of approximately 90 to 100 frames per second. The programs run on a 1 GB DDR-RAM and a dual Athlon XP 1800+ system. The introduced techniques work effectively with interactive applications. Even in just using parts of our approach the appearance of skin can easily be improved.

Our objective was to develop a skin shader for vertex and pixel shader profile 2.0 capable graphic hardware. The virtual agent runs at full screen resolution rendered in real time. In this paper we introduced the anatomical background of the skin. Discussing the development of the geometry and detail normal maps, which are generated from a high resolution polygonal 3D model. Additional bump maps refine our character. The basic color was created as a completely unshaded map. A diffusion map utilized by the lambertian lighting model was used, as well as a backscattering effect to basically smooth the skin. The dimension of the character was enhanced with a self-occlusion map and shadows. To intensify the feeling of skin we added specularity and perspiration, subsurface scattering to emends its deepness. Furthermore in post-process rendering the blurriness can be controlled for subsurface scattering.

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