Modeling and Rendering of Rust

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Abstract

The rusting and weathering phenomena is an important area to consider when one tries to render any physical scene in a realistic manner. The rusting phenomena is especially important because it affects a large number of day to day objects. A proper rendering of rust and weathering is important to give the object a proper decayed look, without which rendering of normal outdoor and indoor scenes does not really look real. But ironically, there has been very little work in Computer Graphics so far in this particular field. Somehow, most of the rendering of rust in Computer Graphics has been accomplished with texture mapping with bump maps to simulate the physical deformation. As a course project of CSE272: Advanced Appearance Modeling, I am trying to model and render rust as it occurs in nature.

1 Introduction

To render realistic images of various real world surfaces it is important to take the natural decay and rust formation effects into consideration. Aging and weathering can take many different forms depending on the surface properties. The effects that are most prevalent in nature are dust accumulation, metallic patinas, moisture, scratches, destructive corrosion and rust formation etc. But, for some reason, in Computer Graphics, there have been very few works on properly rendering the rusting effect on materials. Almost all the rendering of rust uses some kind of texture mapping along with bump-mapping to give the surface a corroded look. In this project, I am trying to model the formation and rendering of rust using Kubelka-Munk theory to simulate multi-layer BRDF computation.

There are several difficulties in trying to model rust. The color and optical properties of rust depends on various factor - the composition of metal, the atmospheric impurities, amount and composition of the moisture etc. These effects makes in almost impossible to determine the optical properties of rust. Even the rust on a simplest metallic surface may have many variations of color and composition throughout.

2 Rust Formation - Overview

Corrosion is the deterioration of a material against its environment. It is an electrochemical process requiring the presence of an electrolyte. For most objects in normal environment a thin layer of water, usually condensed from the atmosphere, is present on the surface of the material and this layer of moisture acts as a electrolyte. The composition of this layer varies with the atmospheric impurities, and the atmospheric humidity level. Usually, at an atmospheric humidity level of 60^o, the layer that forms on top of metallic surfaces is sufficient to produce rusting and corrosion.

2.1 Types of Corrosion

There are two main kinds of corrosion:

1. **Non-Destructive Corrosion:** The products of corrosion create a dense and non-porous layer on the surface of the material. This non-porous layer prevents the atmospheric oxygen and water, which are required for the electrochemical reaction leading to corrosion, from reaching the surface of the metal. Thus the process of further corrosion stops or becomes very slow. This kind of protective layer is called metallic patina.
2. **Destructive Corrosion:** Unlike metallic patinas, the layer that is formed of the products of corrosion is porous. The porosity of such a layer still permits water and oxygen to come into contact with the underlying metal, and thus the process of corrosion continues. This type of corrosion *eats away the metal - hence it is called destructive corrosion. The primary focus of this project is rust - which is an example of destructive corrosion.*

2.2 Different Composition of Rust

Rust formation is primarily an oxidation process involving the creation of many different oxides. What we see as rust is a composition of different metal oxides, with a great variety of chemical structures, all having their own color. The following table summarizes some of the most prevalent chemical structures of rust and their color:

Formulation	**Name**	**Color**
$\alpha - FeOOH$	goethite	yellowish
$\gamma - FeOOH$	lepidocrocite	dark yellow
Fe_3O_4	magnetite	black
$\alpha - Fe_2O_3$	hematite	reddish
$\gamma - Fe_2O_3$	maghemite	brown

2.3 Different Types of Corrosion

There are primarily four different types of rust:

1. **Uniform Corrosion:** The corrosive attack is over the entire surface area. The corrosion rate is almost constant.
2. **Galvanic Corrosion:** Two different metals are coupled in a corrosive electrolyte. The less noble metal tends to corrode proportional to the exposed ratio of the two metals.
3. **Pitting Corrosion:** This type of corrosion produces localized cavities in the material. A pit is usually initiated by a localized surface defect or a local material composition variation.
4. **Crevice Corrosion:** This occurs due to the sudden difference of oxygen accessibility over two parts of the same material. Usually this is found in surface corners.

3 Previous Work

Though there have been lot of study regarding the physiochemical process of the formation of rust, there has not been much work in the Computer Graphics area towards a realistic rendering of rust. Even though environmental decay, rusting etc are an important aspects to consider while rendering realistic real world images, these have been neglected so far, and almost all the rendering of rust is done using texture maps. even though these texture mapping along with bump-mapping gives good results, there is much room of improvement. The primary reason behind this lack of literature might be attributed to the fact that there is so much variation in the composition/color etc properties of rust that it is quite difficult to model the optical properties of rust in a proper manner.

Nevertheless, there have been some work in capturing the environmental decay events in Computer Rendering. Dorsey [2] et al have done extensive work in rendering metallic patinas. Dorsey, Jensen et al [1] described a method to model and render weathered stone. Stephane Merillou et al [8] has tried to model the formation of rust using an empirical decay formula.

Another approach which does not take into account the physio-chemical process of formation of rust is a purely data driven BRDF based approach. Matusik et al [7] have used a simple data driven BRDF model where they construct the BRDF data from several photographs of a material. After that, they analyze the huge amount of BRDF data to find out the space of all BRDFs. They have used this approach to render several materials, one of them being a rust formation. But this simple approach fails to give a proper look of rust - mainly because it does not take into account the deformations of the metallic surface due to the destructive corrosion.

3.1 Simulating Rust Formation

Stephane Merillou et. al. have tried to model the formation of rust in a quantitative manner. In their approach, they have modeled the decay events due to corrosion by using some empirical formulas derived from the data of corrosion mean rate of Steel (g/m^2/year) *vs* atmospheric corrosiveness as a function of time. In their approach, modeling of rust formation was a two step process:

1. **Starting point of Corrosion:** Depending on the material properties, and various other parameters (like micro structure imperfections factor, greasy layer coefficient factor etc) compute the most likely starting point of the corrosion over all the faces of the object.
2. **Compute the corrosion map:** After determining the starting points, compute the corrosion map assuming some spreading model.

After they have prepared the corrosion map, they have used rather simplistic rendering scheme. For non-corroded parts, they have used Cook-Torrance BRDF model for iron. On corroded parts, they have used the BRDF model described in [9] with porosity of rust chosen to be 80%.

This approach, though generates good predictions of rust patters, does not provide good rendering results, primarily because of the assumed simplistic model of rendering.

4 Approach Taken

The initial steps were to familiarize with the complex process of rust formation. Due to the number of different ways of formation and the number of different combinations of rust, and their different properties - it is difficult to model the optical properties of rust.

4.1 First Steps

The very first step at rendering was trying to render the rust without using any physical model of rust formation. So, I used a random noise function to generate rust. As the base metal, I used BRDF data from Wojciech Matusik's website [http://graphics.csail.mit.edu/ wojciech/], and for rust I used the data from the same work. The result was not good. It looked almost like a texture map. It did not look like a good rendering of rusted surface, primarily because the surface looked too flat. The deformation due to the corrosive rusting effect was not captured. I can say even the normal texture mapped rendered images with bump-mapping looked better than that.

4.2 Modeling

The next step was the modeling of physical deformation due to rust formation. Unlike [8], I did not go through a detailed and precise model of rust formation. Rather, I wrote a simple program (*formrust.cpp*) which could generate simple rust patterns like uniform rust pattern, pitting corrosion and some not so good looking flow patterns. This generated some simple looking rust patterns which I have used to show the results of the shader on a simple rectangular metal slab. I have also used the displacement mapping in Dali, which produced quite good results on simplest nurbs geometry like a rectangle. I have been unable to create a complex nurbs model (mostly due to lack of tools to do so). Even though the displacement mapping in Dali is supposed to work with triangle meshes as well, but I could not get it to work. Somehow it kept segfaulting on me every time I ran it.

Taking into account all these factors, I finally decided to present my final rendering of rust on a simple rectangular slab. The displacement mapping worked well on that, and it also shows the rust rendering as well - which was the primary goal of this project.

As the simple rust formation model that I wrote is not realistic enough, I also tried to hand draw a few rust formation models and height maps. I will also include one rendering of a teapot (without the displacement mapping, since it did not work). The rust colors on the teapot looks good though.

4.3 Details of Shader

I have used Kubelka-Munk [6] [4] [5] theory to implement a multilayer rust formation model. The Kubelka-Munk theory gives me the color of a point on the rusted surface, calculated from the height maps and rust layer information at that point. To implement the height maps, I have used one rgb-texture shader for each layer. The optical properties of the layer is given in the terms of scattering and absorption coefficients for red blue and green light. Using these values, I compute what fraction of red green and blue light is reflected off the surface.

To render the surface I have implemented the Cook-Torrance BRDF model. Since Cook-Torrance model depends on the geometry of the surface, to render a point on the surface I have used the geometrical properties (namely the RMS slope of the microfacets) of the topmost layer at that point with non-zero thickness. The index of refraction required to compute the Fresnel term is derived [3] from the Kubelka-Munk reflectance value, assuming the reflectance that Kubelka-Munk theory gives the reflectance at normal incidence.

5 Results

I present my results in this section:

5.1 A Single Layer of Rust

This section shows the result when there was only a single layer of rust.

Figure 1: This is the rendering of the metal plate without any rust formation

5.2 Two Layers of Rust

Modeling the rust using two layers of rust of different optical properties. One slightly darker than the other.

5.3 More than two layers of rust

The following figures show the rendering of rust using three different layers of rust with different optical properties. The topmost layer is yellowish in color. The properties of the bottom two layers are the same as the previous renderings.

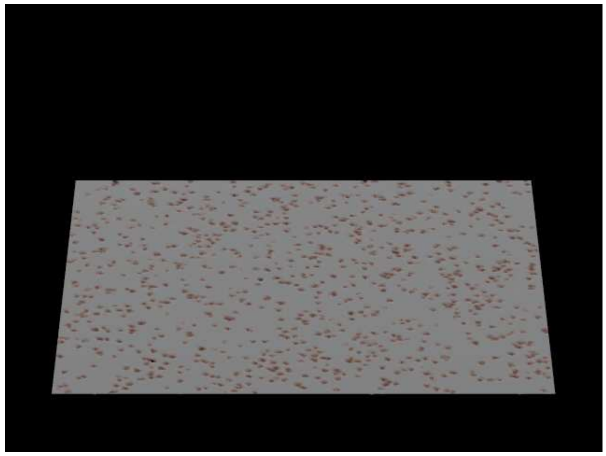

Figure 2: Rendering of the metal plate with a single rust layer - beginning of uniform rusting

5.4 Hand Modeled Rust Formation Map

Since the generated rust models were not able to generate complicated and more realistic rust models, I tried to draw some rust formation models by hand. I applied five layers of different typed of hand generated rust height maps to generate this model of teapot. As the displacement mapping was seg-faulting with triangular meshes, I had turned off the displacement mapping for this rendering. This reduces the realness of the image a little, but still the colors of the rust looks good.

References

[1] Julie Dorsey, Alan Edelman, Henrik Wann Jensen, Justin Legakis, and Hans Køhling Pedersen. Modeling and rendering of weathered stone. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pages 225–234. ACM Press/Addison-Wesley Publishing Co., 1999.

[2] Julie Dorsey and Pat Hanrahan. Modeling and rendering of metallic patinas. In *Proceedings of the 23rd annual conference on Computer graphics and interactive techniques*, pages 387–396. ACM Press, 1996.

[3] Andrew S. Glassner. *Principles of Digital Image Systhesis, V2*.

[4] Paul Kubelka. New contributions to the optics of intensely light-scattering materials - part i. In *Journal of the Optical Society of America, Vol 38, Number 5*, 1948.

[5] Paul Kubelka. New contributions to the optics of intensely light-scattering materials - part ii. In *Journal of the Optical Society of America, Volume 44, Number 4*, 1954.

[6] Paul Kubelka and Franz Munk. Ein beitrag zur optik der farbanstriche. In *Zeitschrift fu"r Technishen Physik 12(112)*, 1931.

[7] H. Pfister M. Brand Matusik, W. and L McMillan. A data-driven reflectance model. In *Proceedings of SIGGRAPH*. IEEE Press, 2003.

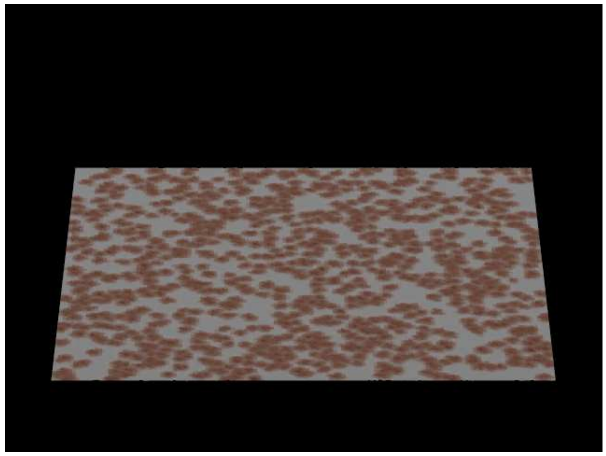

Figure 3: Rendering of the metal plate with a single rust layer - intermediate stage of uniform rusting

[8] Stephane Merillou, Jean-Michel Dischler, and Djamchid Ghazanfarpour. Corrosion: simulating and rendering. In *Graphics interface 2001*, pages 167–174. Canadian Information Processing Society, 2001.

[9] D Ghazanfarpour S Merillou, JM Dischler. A brdf post-process to integrate porosity on rendered surfaces. In *IEEE Transaction on Vizualisation and Computer Graphics, vol 6(4)*, 2000.

6 Appendix: Shader Properties:

The shader is called *kubelka*, and is implemented in file *kubelka.cpp*. There is also another helper shader implemented in that file, named *kubelka_displacement_map*. The second shader takes only one input called *kubelka_shader*, which is a *kubelka* shader, and returns a height map useful as an input to *rgb_to_disp* to automatically generate the displacement map by combining the rust layers' deformations.

These are in inputs to the *kubelka* shader:

```
luxINT,                        "layer",     "Number of Layers"
luxType(luxARRAY|luxSHADER), "heightmap", "Heightmap of the layers"
luxType(luxARRAY|luxFLOAT),  "height",    "Original Heights"
luxType(luxARRAY|luxCOLOR),  "scatter",   "Scattering Coefficients"
luxType(luxARRAY|luxCOLOR),  "absorp",    "Absorption Coefficients"
luxType(luxARRAY|luxFLOAT),  "rms_slope", "RMS slope for Cook-Torrance Model"
```

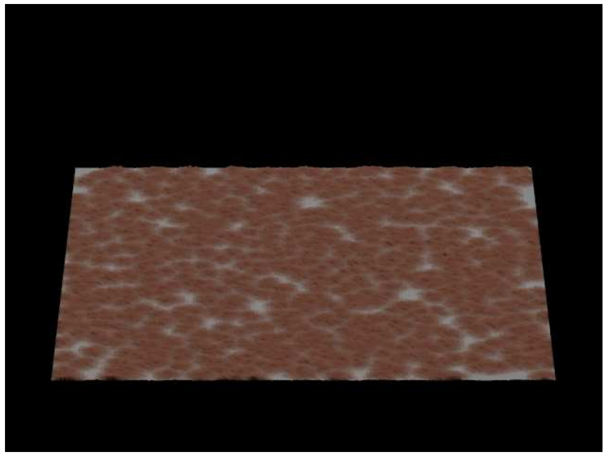

Figure 4: Rendering of the metal plate with a single rust layer - towards the end of uniform rusting

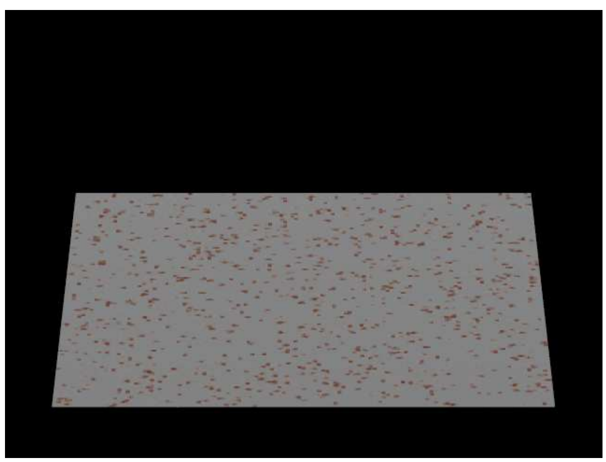

Figure 5: Rendering of the metal plate with two different layers of rust. This rendering is at the onset ot rusting

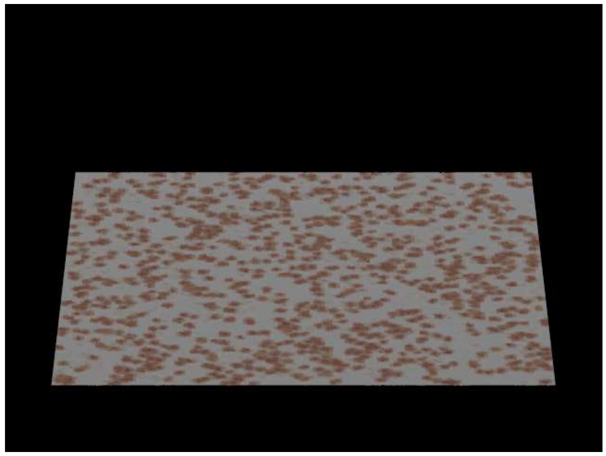

Figure 6: Rendering of the metal plate with two different layers of rust. Intermediate level of uniform rusting

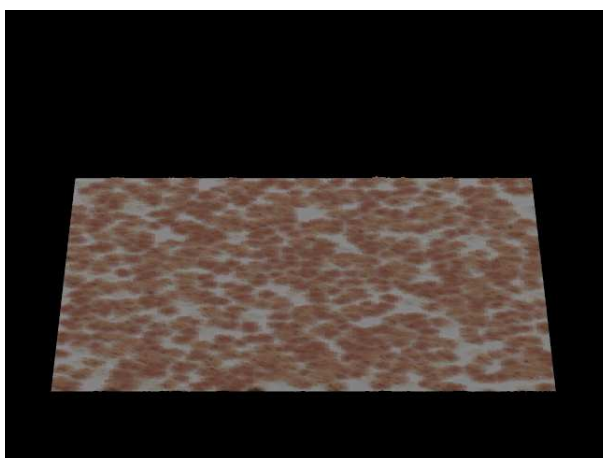

Figure 7: Rendering of the metal plate with two different layers of rust. Some more rusting has occurred after figure 6

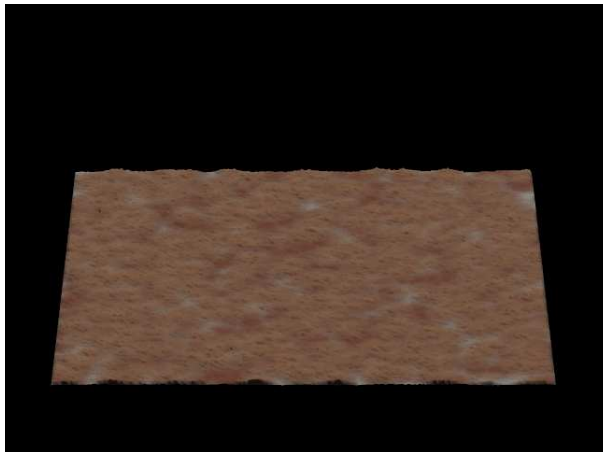

Figure 8: Rendering of the metal plate with two different layers of rust. The rust has completely covered the surface area of the metal sheet.

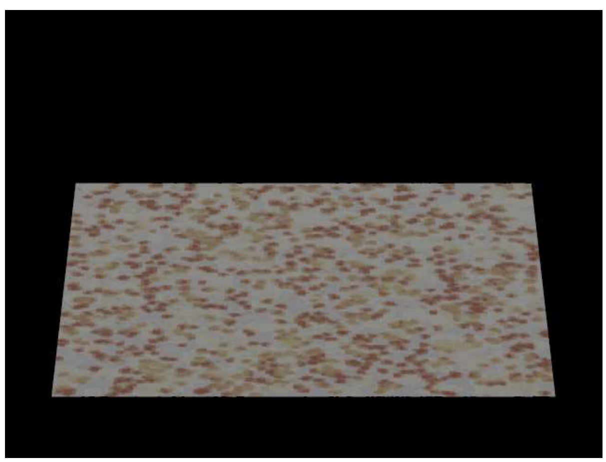

Figure 9: Rendering of the metal plate with three different layers of rust - the rusting has just began.

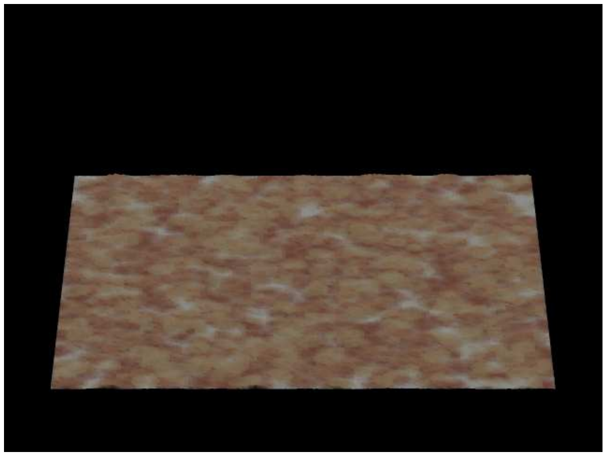

Figure 10: Rendering of the metal plate with three different layers of rust. The rust has completely covered the surface area of the metal sheet.

Figure 11: Rendering of a teapot using five different layers of rust. The displacement mapping is not used - hence the surface looks flat. The roughness of the hand drawn textures is visible though.The rust layers in this rendering are kept very thin.

Figure 12: Rendering of a teapot using five different layers of rust. The rust layers are thicker than previous image [fig: 11]