SIMULATION OF ATMOSPHERIC EFFECTS IN PHOTOGRAPHIC IMAGES

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1. Introduction

One of the objectives of Computer Graphics is to reproduce realistic images using mathematical descriptions. These mathematical descriptions or models employ primitives such as points, lines, and polygons to create an image [Har87]. Using millions of those primitives and changing their color appropriately would reproduce in some extent a "realistic image". Using these primitives and converting them into basic picture elements (pixels), in the screen is what is called *rasterization* [Nei93]. Computer Graphics is being used in movies, computer games, flight simulators and many other places.

On the other hand, image processing usually involves processing images in order to recognize objects in an image, to extract some important information, to compress or to expand an image. It is often desired to process an image so that it can be sent through the world wide web more efficiently or to store it in the smallest space possible using the highest conceivable compression ratio. Another image processing application is cancer detection, by enhancing certain parts of an X-ray image and making the affected part easier to be recognized. Image processing techniques can also determine the quality of an image [Bax94]. Many other applications exist where image processing concepts are used. This research combines the two techniques previously mentioned. Computer graphics and image processing techniques are implemented to develop a software process, that will degrade the quality of a photographic image in a well defined way. This degradation of the image can be varied by changing the visibility in that image. The degradation is accomplished by adding atmospheric effects into the image. These atmospheric effects, such as haze degrade

the image by decreasing the *visibility* of objects within the scene. By this process, objects that are farther than a certain *visibility* range in the scene will not be recognized. What is meant by "*visibility* range" or simply "*visibility*" is that given a parameter of visibility called *meteorological range*, the observer will not be able to distinguish any object farther than that given parameter. According to Duntley the meteorological range is the distance where the contrast transmittance of the atmosphere is two percent [Dun48].

To model this process accurately, several facts have to be taken into account and several assumptions have to be made. The first and most important fact is that the viewing element or the camera performs a perspective projection [Wil96]. This type of image is the one that a human eye will normally see from a "real" scene or from a photograph. For example, when we see the road in front of us, we can notice that the road becomes narrower and sometimes disappearing at a far point, or when we see the electrical poles down the road, that the farther they are, the smaller they become. This is called foreshortening [Nei93]. This fact should be taken into account since real images are going to be processed.

Images can be created using computer graphics techniques, or by using photographic or digital images which must be later processed. For the present application, computer graphics images have been created [Her98] then atmospheric elements, such as haze, smog, dust, (also called *obscurants*), introduced into the image. Photographic images have also been employed [Car97]. Certain software packages such as OpenGL, can also be used to introduce fog into a computer graphical image. The last will model the effect of fog in the image, but it will not do an exact modeling of the effect [Her98], compared to the two previously mentioned techniques where the visibility range can be specified. A method to

accurately specify the meteorological range is needed, taking into account the camera position and lens.

1.1 Previous Research

This research is based on work presented in 1948 by Duntley [Dun48] where he showed that the *visibility* of objects depends on the inherent and apparent luminance which is exponentially dependent on the distance from the viewer to the object. In 1950, Middleton showed that the inherent color shifts to the apparent color exponentially due to the atmosphere [Mid50]. This previous work led to estimate *visibility* by Williams presented in [Will91] where the changes in the contrast were estimated, in black and white satellite images. Zhang [Zha93] extended these results to show that realistic graphical images could be created using these techniques with Cuan [Cua96] showing that an additional constant is required to accurately estimate the visibility. Hernandez [Her98] introduced localized atmospheric effects as well as non-localized atmospheric effects to images that he generated. Carrera [Car97] developed a method of introducing atmospheric effects to real images (photographic images), that were not generated with graphical techniques as done previously. This work is directly based on Carrera's research [Car97]. Enrichments to the previous work are described in the next section.

The great advantage of using a photographic image over a computer generated image is the latter will take hundreds or maybe thousands of polygons to create a realistic image; whereas in the first, the image is already created by the camera.

1.2 Thesis Description

The main purpose of this research is to accurately characterize the atmospheric effects such as fog (haze) or any other obscurants on the *visibility* of the objects. This research involves reading a given image into memory, processing the image to modify the visibility, and displaying the processed image. The theoretical basis relating the camera physics and the image itself was developed, as well as the software that implements the proposed theory to process the images. In order to process an image, certain parameters of the objects in the image are needed, as well as parameters from the camera. From these parameters, an algorithm is employed which estimates the distances from the viewer to objects within the scene and accurately produces a specified *meteorological range.*

This research performs all of the needed transformations taking into account the perspective projection of the camera. Since a camera produces a two dimensional image from a three dimensional scene, the scene is projected onto the film, the image is digitized, and later the image is displayed on the screen. In the case of a digital camera, the scene is stored in memory and later displayed on the screen. This research is part of a long term project, and primarily based from a research done earlier by Carrera [Car97], and the enhancements to that research are:

- The use of the thin- lens equation to model the image and get a more accurate description of it.
- Given the lenses parameters, provide a perspective projection algorithm to correctly describe the objects in the scene.

- The use of transformations from device to world coordinates, in order to be more accurate and well defined, although computationally more expensive, than the earlier research done by Carrera [Car97].
- The use of plane equations to model the objects in the scene.
- The incorporation of OSF/Motif widget and X Windows calls to provide a user interface that will let the user process the images faster and easier.
- The use of the sky modeling proposed by Hernandez [Her98] to model the sky, using a random plane instead of a constant plane on the y-axis.

1.3 Tools

A combination of software packages were used. OSF/Motif and X Windows were used to create the drawing area (where the image is to be displayed) and the user interface, Tk toolkit was used to read the image to the frame buffer, and Mesa Graphics Library version 1.2.8 that emulates OpenGL calls was used to display the image.

The machine used to do all the calculations and rendering was a Sun Microsystems Ultra 1, Creator 3-D ™ workstation running at 167MHZ, with 128 Mbytes of memory, and a 24 - bit frame buffer.

The speed of the machine, the memory and the frame buffer are very important for this research, since every pixel has to be processed and later displayed. The method used for processing the image does not use any scaling because the image can be distorted and requires pixel by pixel processing. The time to process the image could be long if the

features of the machine were diminished. Each pixel requires a series of operations that later will be explained and it creates an overhead that can be compensated by the features of this machine.

1.4 Overview

This research involves processing photographic images. The usual computer graphics approach is to draw a realistic scene, that can be tedious and hard, since hundreds or thousands of polygons are required. By using a real photographic image, this step is avoided.

Digitization of the image is the initial step. Using the perspective projection presented by the camera, the real scene is projected onto two dimensional points of the image (pixels). Latter each point in the image has to be converted into three dimensional points in world coordinates for processing.

Based on the *meteorological range*, and the distance from the viewer to the objects in the scene, the color of each pixel has to be computed. The color of each pixel is determined by computing the distance, and applying the meteorological range to the color of the pixel. The necessary equations for calculating the color of each pixel are shown in the next chapter.

The purpose of this research is to simulate atmospheric effects in an image, and evaluate the visibility and recognition of the objects in it. This work can be used in the creation of special effects, in flight simulators, and in computer games among others.

The work shall be presented in the following manner. Chapter two will present a brief introduction to computer graphics, how the atmospheric effects are simulated, color theory, the algorithm and theory on how to simulate the obscurants. Chapter two is short since a great part of the information has been previously presented in [Zha93], [Car97] and [Her98]. Chapter three covers the camera parameters, thin-lens equation, perspective projection, and modeling of objects using planes. In this chapter also, comparisons between other projections are presented. Chapter 4 describes the software and the algorithms used to process and display the images. Chapter 5 presents the results obtained by this work. Chapter 6 discusses future work.

2. Background and Theory

Before doing any simulation of atmospheric effects, the first thing to do is to examine how these effects occur in nature. Atmospheric effects such as haze, act as a diminishing factor in an image. Depending on the amount of haziness, the objects in the scene can not be properly identified. Haze can act as a filter, that do not block objects, but filters them according to the *meteorological* range. Obscurants attenuate visible light by scattering it, when the light travels from the object to the viewer. Thus, the less the light is scattered, the more clearly the objects will be seen [Mim97]. In a case where there is little scattering, objects can be easily distinguished. A way to measure this scattering is by defining a ***meteorological range***. This range is defined in the following manner: objects that are farther to that *meteorological* range can not be distinguished, that is the color of the object will tend to the color of the obscurant. The meteorological range will take into account the properties of the objects such as color and luminance, and the atmosphere conditions such as the transmittance.

To fully understand the simulation of atmospheric effects, the following concepts will be briefly explained:

- Visibility
- Atmospheric haze
- Transmittance
- Luminance
- Color theory

These terms will be briefly explained in order to give a solid background for the reader.

2.1 Visibility

From the previous discussion, visibility is a measurement of the degree of clearness of the atmosphere [Dun48]. Visibility deals with different factors. These factors are the obscurant through which the light travels (atmospheric haze), quantity of light being scattered when traveling through the atmosphere (transmittance), the distance to the object, and the color, and the brightness of a distant object.

2.1.1 Atmospheric Haze

The Canada Centre for Remote Sensing defines haze as "the process whereby some or all of the energy of the electromagnetic radiation is absorbed and or scattered when traversing the atmosphere"[CCR97]. Atmospheric haze is made from a combination of wind-borne dust, water vapor, aerosols, forest fires, volcanic eruptions, car exhaust, industrial fumes among many others.

2.1.2 Transmittance

The Atmospheric transmittance is the ratio of the transmitted luminance to the incident luminance[Glo96]. Transmittance is the amount of light that can travel through the atmosphere from an observer to an object. This parameter is directly dependent on

obscurants as well as the atmospheric conditions such as humidity, temperature, and many others [Her98]. The transmittance can be calculated in the following way given that the path of sight is horizontal [Dun48]:

$$T = e^{-\beta d / v}$$ ***Equation 2.1***

where:

β is a constant related to the attenuation factor which is equal to the Koschmieder constant which models scattering and absorption, $\beta = 3.912$

d is the distance between the object and the observer.

v is the meteorological range and is defined as "the distance for which the contrast transmittance of the atmosphere is 2%" [Dun48]

2.1.3 Luminance

Luminance is the measurement of light intensity sensed by an observer [Dun48]. Objects have two types of luminance: the *inherent* luminance and the *apparent* luminance. The inherent luminance is the level of luminance sensed at the location of the object and the apparent luminance is the luminance sensed at the viewer location. The latter, is an attenuation of the inherent luminance due to absorption and scattering. We can take as an example, a dark mountain. As the distance from the viewer to the mountain is increased, the mountain's apparent luminance starts to increase until it matches the background luminance, and it is invisible [Dun48].

W.E Middleton derived an equation to calculate the apparent luminance of a given object given its location (x, y) [Mid50]. The following is derived from the same equation with the only difference being that it takes into account three dimensional space.

$$B_{app}(x0,y0,z0) = B_{inh}(x1,y1,z1)T_{01} + B^*_{01}(1 - T_{01}) \qquad \textit{Equation 2.2}$$

where:

$B_{app}(x0,y0,z0)$ is the apparent luminance of the given point.

$B_{inh}(x1,y1,z1)$ is the apparent luminance measured at point $(x1,y1,z1)$.

T_{01} is the beam transmittance of the atmosphere along the path of sight.

B^*_{01} Path luminance, the accumulation of all the scattered light along the path of sight.

The following figure graphically shows the effect of the equation 2.2

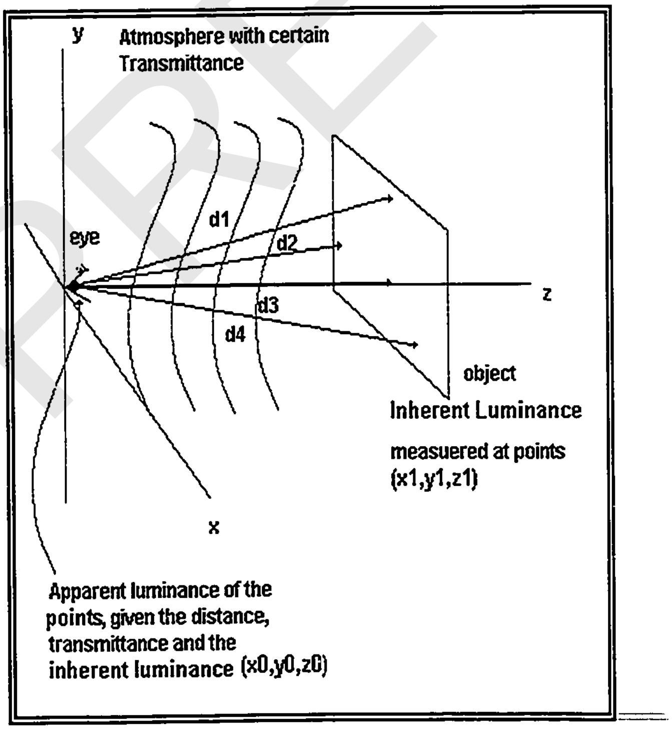

Figure 2.1 Apparent luminance of an object