Realistic Visualisation of the Pompeii Frescoes

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ABSTRACT

Three dimensional computer reconstruction provides us with a means of visualising past environments, allowing us a glimpse of the past that might otherwise be difficult to appreciate. Many of the images generated for this purpose are photorealistic, but no attempt has been made to ensure they are physically and perceptually valid. We are attempting to rectify these inadequacies through the use of accurate lighting simulation. By determining the appropriate spectral data of the original light sources and using them to illuminate a scene, the viewer can perceive a site and its artefacts in close approximation to the original environment. The richly decorated and well-preserved frescoes of the House of the Vettii in Pompeii have been chosen as a subject for the implementation of this study. This paper describes how, by using photographic records, modelling packages and luminaire values from a spectroradiometer, a three dimensional model can be created and then rendered in a lighting visualisation system to provide us with images that go beyond photorealistic, accurately simulating light behaviour and allowing us a physically and perceptually valid view of the reconstructed site. A method for capturing real flame and incorporating it in a virtual scene is also discussed, with the intention of recreating the movement of a flame in an animated scene.

KEYWORDS

Computer graphics, reconstructions, archaeology, visualization, visual perception.

1. INTRODUCTION

The application of computer graphics to the field of archaeology is becoming more commonplace. From providing the archaeologist with an aid to interpretation to giving the public an animated glimpse of the past, the use of realistic graphics provides a powerful tool for modelling multi-dimensional aspects of archaeological data. Sites and artefacts can be reconstructed and visualised in 3D space, providing a safe and controlled method of studying past environments. This new perspective may enhance our understanding of the conditions in which our ancestors lived and worked. To date, however, limitations have been imposed with regard to the validity of these reconstructions [1]. The concept of realistic image synthesis centres on generating scenes with an authentic visual appearance. The modelled scene should not only be physically correct but also perceptually equivalent to the real scene it portrays [10] and this research seeks to address the problems encountered in the realistic simulation of archaeological sites.

Today our world is lit by bright and steady light, but past societies relied on daylight and flame for illumination. There is well-documented archaeological evidence for the use of flame; the presence of hearths, the remains of lamps and historical documentation where it exists all provide a source of information regarding the use of artificial light. If we consider our perception of the world we inhabit today and compare the modern lighting with that of the past, it is evident that there are significant differences in how it appears [2]. It would seem, therefore, that the photo-realistic site reconstructions often produced are flawed in regard to lighting conditions. Although they may look "real" their validity cannot be guaranteed as no attempt has been made to use physically accurate values for ancient light sources and surface reflectance. They owe more to an artist's imagination than to an interpretation based on numerical simulation. The commonly used software packages base the lighting conditions on daylight, fluorescent light or filament bulbs and not the lamp and candlelight that would have been used in the past. In some cases the reconstructions are lit with physically impossible lighting values. Our perception of past environments should consider the lighting conditions of that time - the use of natural daylight and the use of flame in a variety of forms. The different fuel types of each of these sources will affect our perception of a scene, and this needs to be taken into account [6]. Our perception of colour is affected by the amount and nature of light reaching the eye, so by simulating the behaviour of the appropriate type of light in an environment it should be possible to demonstrate how it may have looked in the past. The goal is to produce images that recreate accurately the visual appearance of an environment illuminated by flame.

2. LUMINAIRES

The luminosity of flame is due to glowing particles of solids in laminar flux, the colour of which is primarily related to the emission from incandescent carbon particles. A typical fuel/air wick flame consists of three distinct zones: the inner core, the blue intermediate zone and the outer cone [5]. The different zones of the flame produce different emissions depending on the fuel type and environment conditions.

Previous work on modelling flame has focussed on large-scale flames such as fires [4], fireballs and explosions [15] [13] or more generic flames [17][18][19]. Inakage introduced a simplified candle flame model [7], which Raczkowski extended to incorporate the dynamic nature of the flame [14]. In this study we are interested in the perception of objects illuminated by different fuel types.

2.1 Building the luminaires

The acquisition of valid experimental data is of vital importance as the material used may have had a significant influence on the perception of the ancient environment. In consultation with the Department of Archaeology at the University of Bristol, various light sources were recreated. These included processed beeswax candles, tallow candles (of vegetable origin), unrefined beeswax candles, a selection of reeds coated in vegetable tallow, a rendered animal fat lamp, and an olive oil lamp.

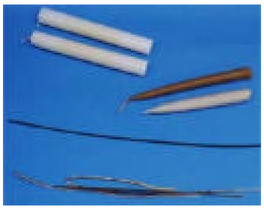

Figure 1. Experimental archaeology: reconstructing ancient light sources

The appropriate sources for this project were judged to be olive oil lamps, the most readily available fuel type for that area. Water was added to some of the lamps to keep them cool whilst being carried and to stop the oil from sticking. Salt was added to others to make the oil burn for longer.

Detailed spectral data was gathered using a spectroradiometer, allowing us to measure the absolute value of the spectral characteristics without making physical contact with the flame. This device can measure the emission spectrum of a light source from 380nm to 760nm, in 5nm wavelength increments, giving an accurate breakdown of the emission lines generated by the combustion of a particular fuel. The measurements were performed in a completely dark room and the device was aimed at a board coated with a 99% optically pure Eastman Kodak Standard white powder, which diffusely reflects the aggregate incident light. Ten readings were taken for each lamp type and an average was calculated. This data can be used to create an RGB colour model for use in rendering the scene.

3. THE POMPEII FRESCOES

The House of the Vettii in Pompeii is one of the best-preserved and decorated buildings in this World Heritage site, and is the most frequently visited building in Pompeii [12]. The rich colours and extensive use of artistic techniques such as *trompe l'oeil*, along with its magnificent state of preservation draws millions of visitors through its rooms each year. However, the impact of time and tourism on such a site has led to serious deterioration. Computer reconstruction of the House of the Vettii allows us to view it as it might have been when it was in use before the eruption of Vesuvius in AD 79.

The room chosen for the study was an *oecus*, or reception room, which opens onto a colonnaded garden. The high quantity of red and yellow pigments in this room was of specific interest to our study. Its three walls are richly decorated by intricate frescoes in the IV Style, also termed the "illusionist style" (Figure 2). Descriptions of how frescoes are created appear in Classical literature. It involves the application of colour pigments to wet plaster so that the plaster and the paint are merged and dry together, creating a permanent and vivid display. The fact that the House of the Vettii was immediately and sympathetically restored around the frescoes has meant that the paint colours have been well preserved.

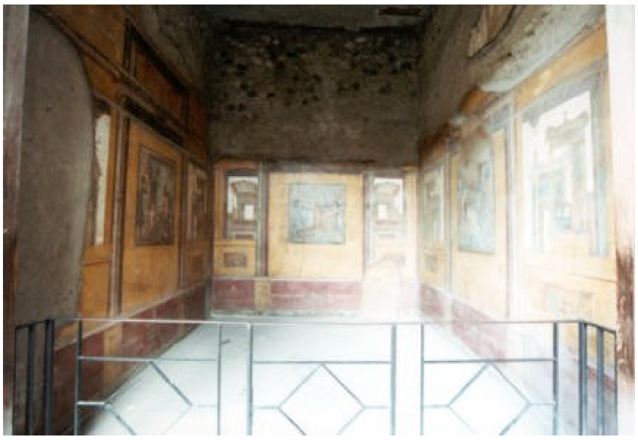

Figure 2. The room as it appears today

The frescoes in the room were recorded photographically. A colour chart was included at either side of each photo to permit calibration, identify illumination levels and allow any gradient in the light to be calculated. Using a scale plan of the room a 3D model was generated.

3.1 Converting the luminaire data

The resulting luminaire data obtained from the spectroradiometer was then converted to RGB values to enable display on a computer monitor. It is essential, when converting the detailed spectrum data from the spectroradiometer into values representing the red, green and blue portions of the spectrum, that this conversion is calculated in a perceptually valid way, as defined by the CIE (Commission International de l'Eclairage) 1931 1-degree standard observer[1].

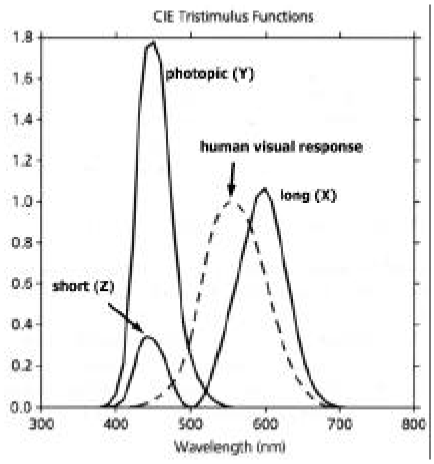

Figure 3. CIE Tristimulus functions

Figure 3 shows the functions for the X, Y and Z channels. The Y channel measures the luminance of a source, and the X and Z channels measure the chromaticity. This information is more useful when broken down as follows:

If we let $x = \frac{X}{(X+Y+Z)}$ and $y = \frac{Y}{(X+Y+Z)}$

then we can calculate the exact colour values for the red, green and blue sections of the spectrum, disregarding luminance. For a canonical set of VDU phosphors: RED(x,y) = (0.64, 0.33); GREEN(x,y) = (0.29, 0.60); and BLUE(x,y) = (0.15, 0.06) [22].

Radiance [22], a lighting visualization system, was used to render the images. It contains a function (*rcalc)* to convert the xyY coordinates to RGB values. Radiance then takes these RGB values and accurately simulates the associated light source behaviour in a modelled scene.

[1] This system specifies a perceived colour as a tristimulus value indicating the luminance and chromaticity of a stimulus as it is perceived in a 1-degree field around the foveal centre.

3.2 Modelling the flame

The type of flames that we are interested in are categorised as diffusion wick flames, in which heat transfer from the flame cause a steady production of flammable vapour. Observations from the reconstructed light sources showed that all of the flames were small and (ignoring the effect of air turbulence for now) fairly steady.

Rather than attempting to model the shape of the flame accurately for this initial stage of the project, video footage of the real flames from the reconstructed light sources was processed using computer vision techniques, the shape of the flame extracted and the real flame incorporated in the virtual scene. To capture the flame a 'blue screen' technique was used. This simple technique is widely employed in the film industry, and is used to cut an object from its background surroundings. Filming the flame against an evenly coloured, matt background enables thresholding of each frame, which is used to identify and dismiss a background colour, effectively separating the flame from any unwanted parts of the scene. The background colour should be chosen so that it does not occur within the foreground. As the intermediate zone of the flame is generally blue in colour, a green screen rather than a blue screen should be used (Figure 4).

Figure 4: Video still of the flame against a green screen

Thresholding is the process of identifying a range of colour, and changing all areas within an image that fall into this range to another specified colour. Simple, solid objects can easily be separated from a background, but a flame produces some of its own difficulties. It is useful to have static and even lighting on the background to simplify the thresholding process. Filming a flame creates a problem in that it is itself a light source and may therefore disrupt otherwise static lighting, producing unwanted background lighting effects. Parts of a flame may be translucent or partly transparent, so seepage of the background colour into what we identify as the flame may occur. This is difficult to avoid, but we can compensate for this at a later stage by deliberately seeping the background colour of the modelled scene into the flame. By splitting the video stream into separate frames an animated sequence can be achieved.

Once an object has been separated from its original background, it can then be placed in a new scene. If used sensibly, the object can be blended into the new background to give the appearance that this is an unaltered, original scene.

The illumination of the flame in the environment was achieved by approximating the shape of the flame by a series of *illum* spheres [22], as shown in figure 5(a) and included in a virtual scene 5(b). The material type *illum* is an invisible light source. When viewed directly, the object made from *illum* is invisible but it still emits light. The number and size of the spheres can of course be varied to achieve a better "fit" to the shape of the flame for each frame of the video sequence. Once the images have been rendered the original picture of the flame is pasted into the scene. Some care needs to be taken here to accurately position the original picture of the flame and blend it into the scene.

Figure 5: (a) Simple luminaire model (b) real flame in virtual environment

A set of programs was written to take a sequence of flame pictures as input and to output data representing the flame, to any desired level of accuracy [16]. This provides an efficient method of incorporating the real flame in a synthetic image.

3.3 Changes in perception in flame-lit conditions

Conversion of the spectral data to RGB does of course lead to an approximation of the colours present. In future, for more accuracy we will need to consider calculating the convolution of the emission spectrum of the light source with the reflectance curve of the material under examination. However, even with the approximation, significant perceptual differences related to fuel type are achieved. These simulations can be validated with real scenes [11]. Figure 6 shows a test scene including a MacBeth colour chart illuminated with (a) a 55W electric bulb, (b) an olive oil fuel. The difference in fuel type has a discernible effect on the appearance of the MacBeth chart. The apparent differences indicate that it is important for archaeologists to view such artwork under (simulated) original conditions rather than under modern lighting. It is of course impossible to investigate these sensitive sites with real flame sources.

Figure 6: The effect of different fuel types

(a) modern (b) olive oil

The initial results of this on the Pompeii frescoes can be seen below. It is noticeable that the lamp-lit scenes (Figures 7b – 7d) can be perceived as warmer in appearance when compared to the modern light (Fig. 7a), with the yellow and red pigments particularly well emphasised. The appearance of the three-dimensional *trompe l'oeil* art is also influenced.

Figure 7. Clockwise from top left: (a) modern lighting (b) olive oil lamp (c) olive oil lamp with salt (d) olive oil lamp with water

These are preliminary images only, and current work involves the addition of models of appropriate Roman furniture and artefacts to the scene. This will not only create a more realistic scene, but will allow archaeologists to investigate the appearance of objects under their original lighting conditions. It is important to remember that a reconstruction is only one glimpse of many valid interpretations. Various configurations of lamps are also being modelled to provide a number of possible scenarios.

4. FUTURE WORK

In flame-lit environments the range of light can vary greatly over short distances. Human vision ranges over nine orders of magnitude whereas the dynamic range of most display devices covers only two, thus some form of compensation is required to map the light-dependent way we will view a scene [20][3][21].

The ultimate aim of realistic graphics is the creation of images that provoke the same response and sensation as a viewer would have to a real scene, i.e. the images are physically and perceptually accurate when compared to reality. Given that the aim is to create an environment that can be perceived as real, future work involving tone mapping will allow us to gain more perceptual accuracy of the scene. Furthermore, the use of an eyetracking device to measure involuntary eye movement will enable us to define which areas of the room are emphasised under different lighting conditions, and will give us an insight into the effectiveness of the three-dimensional paint techniques employed in the frescoes. Above all this, the need to establish a metric for realism through comparison with reality is essential if the images are to be of full use [11], and work in the future will attempt to quantify how "real" our reconstructions actually are.

5. CONCLUSIONS

To date, the work has provided us with a means of viewing a reconstructed site under its original lighting, and allows us to place a real flame in a virtual environment. The method of incorporating a real flame in a rendered image also provides for movement by means of a sequence of frames, so that an animation of the scene can have a dynamic flame inserted in it.

This method of visualization of past environments provides a safe and controlled manner in which the archaeologist can test hypotheses regarding perception and purpose of colour in decoration and artefacts. Computer generated imagery indistinguishable from the real physical environment will be of substantial benefit to the archaeological community, and this research is one method of moving beyond the current trend of photo-realistic graphics into physically and perceptually realistic scenes which are ultimately of greater use to those investigating our past.

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