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High Dynamic Range Display of Authentically Illuminated Byzantine Art from Cyprus

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Abstract

High-fidelity computer reconstructions of cultural heritage sites attempt to create a faithful representation of the past physical environment. This includes modeling the scene to high precision, and accurately simulating the distribution of authentic light energy within the scene. This does not, however, ensure that the displayed image will have a high fidelity visual appearance due to the limited dynamic range of typical computer displays. Such displays only have a range of about two orders of magnitude between minimum and maximum luminance. A well-designed cathode ray tube (CRT) monitor may do slightly better than this in a darkened room, but the maximum display luminance is only around 100 cd/m^2, which does not even begin to approach natural daylight levels of approximately 105 cd/m^2. Furthermore, their inability to display "true black" means that standard displays also struggle to show low-light images accurately. In this paper we compare images of computer reconstructions of Byzantine art from Cyprus illuminated with simulated modern lighting and the candle light which was present in Byzantine times on both a traditional and a novel High Dynamic Range display.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation - Display Algorithms I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Color, Shading, Shadowing, and Textures

1. Introduction

The Byzantine empire was an alliance of a vast numbers of cultures, and grew out of the Eastern Roman Empire. It lasted for more than 1100 years until 1453 when the Turks occupied Constantinople, the capital. Despite the manifold of different cultures within the Byzantine Empire, a common architecture and sacred art style developed. During Byzantine times, Cyprus followed closely the art and cultural trends of the capital, Constantinople, with especially high-quality art. Today it is in this tiny, former rich and peaceful province of the Byzantine Empire that many of the most precious surviving relics of Byzantine art are to be found. This is due to the fact that Byzantine master painters visited Cyprus to paint and teach their art with much painting of church interiors and icons. Another reason is that Cyprus achieved a state of neutrality in the 7th century strife between Byzantium and Islam and therefore remained unaffected by the Iconoclastic edicts of the Byzantine Emperors, which resulted in many pieces of art elsewhere being destroyed.

In this paper we examine the perception of one well known icon, the Icon of Christ Arakiotis, from the Church of Pantocrator of Arakas from Lagoudera. The icon is currently displayed in the Byzantine Museum & Art Gallery, Bishops Palace in Nicosia, figure 1. The icon is dated from the end of the 12th century and is painted with tempera and gold leaf on a wood panel, which was typical for artefacts primarily intended for ritual or ecclesiastical use during the Byzantine period.

Nowadays the surviving works of art are, mostly, carefully preserved in museums. Here they can be viewed under modern lighting, and thus not under the lighting conditions that would have been used in Byzantine times. The amount and nature of the light in an environment directly affects our perception of objects within our field of view. High-fidelity computer graphics techniques can enable us to recreate the authentic illumination of the past [DC01, SCM04], enabling

Figure 1: *Capturing the data at the Byzantine Museum & Art Gallery, Bishops Palace, Nicosia, Cyprus.*

Figure 2: *Example of Byzantine candelebra with modern lighting replacing the candles.*

us to investigate how the icon may have been perceived in the past.

2. Recreating the Past

Computers are now regularly used to recreate the past, resulting in reconstructions of vastly varying quality. In fact the question of what level of realism should be incorporated in virtual archaeology is the subject of much ongoing debate, for example [Spi88, RS89,Mol92, MR94, Rya96, FSR97, RR97, Gil99, Bat00, EI00, Kan00, Mar01, CDB*02]. To date there are in fact very few reconstructions that attempt to authentically represent how a site may have been appeared in the past. To achieve such a high-fidelity result, it is crucial to incorporate into the computer model as much as possible of the physical evidence that may have affected the perception of a site. Failure to do so runs the real danger of the virtual reconstruction actually misrepresenting the past.

3. Byzantine Art

Sacred pictures (icons, frescoes and mosaics) had a great importance for the Byzantines, reaching far beyond mere decoration objects or reproductions of persons and holy scenes. These kinds of pictures were believed to actually directly represent, for instance, a certain holy person including their personal features and could therefore even have identical protective or healing powers as the original. This belief led to the strict organisation of the sacred sites, with the pictures in focus [The01]. In order to enable a certain perception and to achieve as much interactivity as possible between the viewer and the holy persons pictured, the following was prescribed: the church architecture; the ideal position of an average-sized viewer in the church building; the position of the pictures depending on whom they represent in the religious hierarchy; the use of directed illumination to achieve a certain visible perception of an artwork; and the amount of light and the use of light sources, which varied depending on whether a special celebration was being held or not [Bel90].

The Byzantines were much preoccupied with the use of gold and favoured it extensively in their churches. In the icons, massive wall and ceiling mosaics and frescoes, the use of gold was not only symbolising immortality and the supernatural but was meant to illuminate the pictures from "within". This lighting effect in combination with certain architectural elements of the churches was used to create certain illusions, including the holy people on the cupola mosaics seeming to step out of the golden background, approaching the viewer [HJK96]. Gold was not only used for the pictures, but also for candlesticks: with churches having masses of candles, both in ornate floor candleholders and in hanging candelabra, such as shown in figure 2. Byzantine architects in fact paid careful attention to the use of direct and indirect lighting in certain parts of the church building, depending on the firmly defined religious value of the respective space [The01]. This religious value was also symbolised by the architectural form and the use of pictures. For example, the cupola, being the most characteristic architectural element of the Byzantine churches, should be a direct representation of heaven, therefore it had to be illuminated by as much light as possible, including the generous use of reflecting gold [HJK96].

4. Authentic lighting

Byzantine churches looked very unimposing from the outside. Made from local stone, there was no use of paint or precious materials to enhance the exterior. This was in (deliberate) stark contrast to the very rich interiors with the abundance of dramatic highly-ornate objects, designed to engage the viewer to approach God [Pee04]. Deliberate use was made by the architects of light and shadow to direct a viewer's attention within the church and symbolically rep-

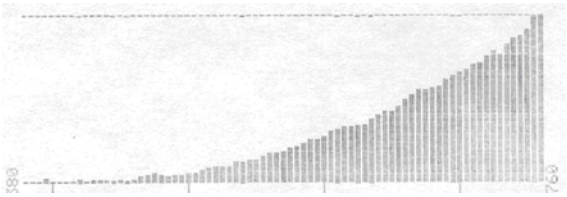

Figure 3: *Spectral profile of a beeswax candle [RC03].*

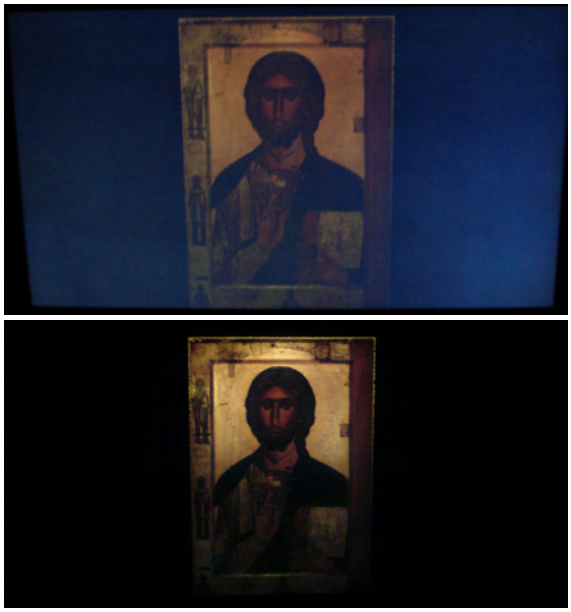

Figure 4: *The icon displayed on (top) a standard LCD display, (bottom) the HDR display.*

resent the sacral hierarchies, with "heaven" in the better lit upper parts of the church. Daylight was the primary form of lighting in the early period Byzantine churches by means of openings in the upper parts of the walls. The middle Byzantium period is characterised by less openings for natural lighting and thus a greater dependency on oil lamps and candles [The01]. Manuals, known as typicons, specified in great detail how the artificial light was to be positioned in a church. This was to highlight the clear difference between "divine light" and "profane darkness". The careful positioning of the lighting was also used to maximise the effect the sparkle from the precious materials, such as the gold and silver of the icons, mosaics and frescoes would have on the viewers drawing them into contemplation [Pee04].

A computer reconstruction of a flame lit environment should not only incorporate the accurate spectral profile of the fuel being burnt, but also the manner in which the flame may move over time [DCB02, Rac96, RC03, BRR*06, BLR*06]. The acquisition of data on the nature of the flame is thus of vital importance as the material used may have

Figure 5: *PTMs of icon with light from left, middle and right.*

had a significant influence on the perception of the ancient environment [CLR, DCB02]. Experimental archaeological techniques were used to build replica candles and oil for the lamps using authentic materials. These candles and oils were then set on fire and the detailed spectral data of each flame type measured using a spectroradiometer, which is able to measure the emission spectrum of a light source from 380nm to 760nm, in 5nm wavelength increments. Figure 3 shows the spectral profile for a beeswax candle. Physically based lighting simulation systems, such as Radiance [WS98] are able to make use of this wavelength information to achieve high-fidelity results. [MCT*00, RB04].

The goal of this work is to relight the icon so that it appears under simulated modern lighting as it can be seen in the museum today, and simulated candle light as it may have been seen in the past. Many images of the icon were captured from a fixed camera position, with the icon illuminated from a number of different light positions. This was to enable a PTM image, [RM07], to be captured so that we could also investigate how the position of the lighting may have affected the appearance of the icon, figure 5. Since all photographs taken of the icon also contain the illumination under which the pictures were taken, in order to determine the nature of the illuminant and from this be able to derive an illumination neutral image to subsequently relight, a number of pictures also included a Macbeth Colour chart. The program, macbethcal in Radiance was then used to directly compute the correct colour and brightness.

5. High Dynamic Range displays

The dynamic range of a display typically refers to the maximum range between the darkest and brightest parts that can be displayed for any image. A conventional CRT monitor is capable of a ratio of about 600:1, while a good quality flat-panel LCD can achieve 500:1. High Dynamic Range (HDR) displays are capable of contrast ratios of 200,000:1. The substantial difference in brightness is achieved by projecting through a standard high definition LCD panel with an array of ultra-high brightness white light-emitting diodes (LEDs) which can be controlled individually. Not only are these displays significantly brighter that existing monitors, but, more importantly for the work in this paper, they are more than

Figure 6: *Simulating dark adaptation. Once the candles are blown out, our eyes gradually adapt to dark [LSC04].*

ten times darker than any commercially available display, achieving a black level of 0.015 cd/m^2 [DR3].

As figure 4 (top) shows, the inability of a standard LCD display to "true black" means that the displayed image is surrounded by the "glow" of the LCD, while this does not occur with the HDR display, figure 4 (bottom).

5.1. Eye Adaptation

A key component that any system which attempts to reconstruct low light environments needs to consider is dark adaptation. The human eye is capable of seeing a huge range of light intensities ranging from daylight illumination levels of around 108 cd/m^2 to night luminances of about 10^{-6} cd/m^2. However, as the actual cells of our eyes have a much more limited range, our eyes have to adapt in order to cope with these large illumination ranges.

If there is a sudden increase in light in our environment, our eyes "light adapt". This is typically very quick, in the order of seconds, and results in a loss in the visual system's sensitivity. Dark adaptation, when there is a sudden decrease in light, is a much slower process. During this process, which can last tens of minutes, the visual system recovers sensitivity which we experience as temporary blindness. The actual time taken for both light and dark adaptation is mainly a function of pre-adapting luminance and pre-adapting time and it is different for the cones and rods in our eyes [HF86]. When simulating eye adaptation, care needs to be taken to account for important effects such as colour sensitivity and visual acuity variation [LSC04]. Figure 6 shows a simulation of dark adaptation.

6. Results

Figure 7(a) shows the icon lit by a simulated modern halogen light while figure 7(b) shows the same icon lit by simulated beeswax candles. Of course it is not possible to accurately reproduce the images in this paper, but it should be clear from what can be seen, that there is a clear perceptual difference between the two icons. Under modern lighting, the gold which makes up the background and halo is very bright and the details of Christ very clear. In the candle lit icon, the gold from the background appears to "glow", and although the details of Christ are not as clear, there is a far-more three-dimensional quality to the icon.

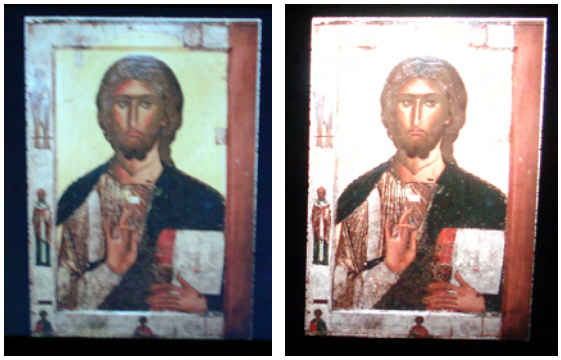

Figure 8: *Icon lit by simulated modern lighting shown on (left) the LCD display (right) the HDR display.*

Finally, figure 8 shows photographs taken of the icon lit by simulated modern lighting as it appears on an LCD display (left) and on the HDR display (right).

7. Conclusion

In the Byzantine period, the layout and lighting of the icons, frescoes and mosaics in the churches were carefully regulated to achieve a significant perceptual, even spiritual response from the viewer. Many centuries later it is simply not possible to achieve this same perceptual experience as few Byzantine churches remain, and those that do, have undergone many changes over the years. Furthermore, many of the precious surviving works of art are now safely ensconced in a museum. In both cases the art work can now be viewed only under harsh modern lighting, and not the candle and oil lamp lighting conditions of the past. Physically based computer reconstructions can enable us to accurately recreate the flame-lit conditions of the past. However, as we have shown, the perception of even these high-fidelity reconstructions is substantially let down by current display technology. Modern HDR displays which are 30 times brighter,

Figure 7: *Icon lit by simulated modern lighting (left) and lit by simulated beeswax candles (right).*

and, more importantly for our purposes, 10 times darker than traditional displays, offer the real possibility of showing just how these icons may have appeared during Byzantine times. Future work will make use of high-precision eye-tracking to investigate just how a person views the icon under modern and ancient lighting conditions to see if there is any significant temporal and spatial differences. Furthermore, the icon would have been viewed in the context of the whole church, and not in isolation. A detailed model of a Byzantine church is being created to explore the full three-dimensional experience of a Byzantine environment on a HDR display.

Acknowledgments

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