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HDRI AND RETINEX TECHNIQUES APPLIED FOR CULTURAL HERITAGE DOMAIN

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Abstract: The paper presents a comparison between digital images of mural paintings acquired using High Deffinition Range Imaging techniques and images that result after the processing of the images of murals taken under spatial and spectral variations of the illumination with the Retinex algorithm. The processing of mural painting images with the Retinex algorithm elevates their quality to a higher status, comparable with the quality of the images acquired with the HDRI technique. We consider that both techniques, Retinex and HDRI, should become part of the modern products, dedicated for cultural heritage domain.

Keywords: *High Deffinition Range Imaging, Retinex algorithm.*

I. INTRODUCTION

Old digital images, even those taken under poor illumination conditions or with obsolete digital cameras, carry within important information for art conservation-restoration: details that were lost in time, colors that could tell the restorer the nature of the used pigments, for example.

Digital images of mural paintings, especially, suffer from a significant loss in visual quality as compared to the same images perceived by the human eye. Some of the causes of this problem are the spatial and spectral variations of the illumination, due to the specificity of those artworks: the impossibility to separate them from the substrate and their large dimensions. Another cause lies in an ability of the human eye that lacks to all digital cameras, namely the ability to adapt and to assign colors according to the relative balance of short, medium and long wavelength across the whole visual field. This ability, known as Color Constancy, is desirable to all artificial systems, and was modeled by Edwin Land in his Retinex model [1]. Color Constancy allows humans to separate the illumination from the reflectance and compensate for the non-uniform lighting conditions.

Ensuring the quality of images [2] has become a common concern in most technology related fields, such as testing, processes optimization, monitoring or inspection, but also in fields related to biology, medicine or art. One of the newest data acquisition methods with great applicative potential is the High Dynamic Range Imaging (HDRI).

The HDRI technology is described in [3] together with many fields of application, both in technology and in art. Plasma image acquisition [4] is such an example of HDRI use. In [5] is described another application of HDRI, for quality inspection of metal-rubber profiles, method which has an important advantage, due to the elimination of the different light reflections given by the profiles. HDRI is also used for sonar images enhancement [6], where it showed the ability to eliminate the noise generated by other sonars. In the military field there is a great interest on HDRI, one paper [7], for example, addressing the problem of creating HDRI images by postprocessing, method which would not require the replacement of the surveillance hardware. The same problem is addressed by [8], where the authors also proposed a postprocessing algorithm for acquiring HRDI image quality. In the medical field [9] proposes the use of HDRI for mammography enhancement. In art field [10] proposes the use of HDRI interior images with a set of stereo DSLR cameras in order to obtain a 3D model of the interior of a monument.

Both HDRI image acquisition technique and Retinex algorithm have the same goal, to ensure better image quality with respect to detail and colors. In [11] one can find a development of the Retinex algorithm with respect to color information, while in [12] Retinex is used to improve the quality of foggy images. Having the same goal, the two different techniques could be applied to the same image, subject explored by [13, 14]. Both techniques are of great interest for the developers of art conservation-restoration dedicated software, such as the Cultural Heritage Image Processing tool, CHIP [15].

Our prior work addressed the problem of Retinex algorithm use for image enhancement in art conservation-restoration, as compared to the intensively used histogram equalization algorithm [16]. The present paper intends to draw a comparison between the results obtained by using the Retinex algorithm for the enhancement of mural painting images and the images of the same murals acquired with HDRI technique. The images used for this paper represent murals from the oldest orthodox church from Râşnov, Romania, which is considered to be the first church built by the Basarab royal family in Transylvania [17], dated 1384.

II. HIGH DEFFINITION RANGE AND RETINEX ALGORITHM

High-dynamic-range imaging (HDRI or HDR) techniques provide higher dynamic range from the imaging process, compensating the loss of detail in bright or dark areas of a

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picture by acquiring multiple images at different exposure levels. The images are then merged together, so that the final effect is the capture of a greater dynamic range between the lightest and the darkest areas of an image. The first successful HDRI attempt dates back to 1850 and was done by Gustav LeGray who combined two film negatives, one for the sky and the other for the sea, and created a single paper positive representing a marine landscape.

Light intensity can be described both in terms of incident and reflected light; and all contribute to the dynamic range of a scene. High variation in reflectivity may actually have a greater dynamic range than scenes with large incident light variation. Overall, the dynamic range of a digital camera can therefore be described as the ratio of maximum light intensity measurable (at pixel saturation), to minimum light intensity measurable (above read-out noise). The most commonly used unit for measuring dynamic range in digital cameras is the f-stop, which describes total light range by powers of 2. The human eye can actually perceive a greater dynamic range than a camera. If we consider the situations where our pupil opens and closes for varying light, our eyes can see over a range of almost 24 f-stops [22]. This is possible because the human visual system has many adaptation mechanisms, which makes human eyes extremely adaptable to variations in the incident or reflected light.

One such important adaptation mechanism of the human visual system is the Color Constancy, which allows that the perception of the objects gives rise to similar perceptual experiences regarding the color, despite important variations in observation conditions [1, 18]. If we consider an object characterized by its reflectance, *R(λ)*, and an observer that is looking at the object, the spectral distribution of the reflected light that reaches the eye of the observer is given by the following equation:

$$C^x(\lambda) = E(\lambda) R^x(\lambda) \tag{1}$$

where *E(λ)* is the spectral distribution of light and $R^x(\lambda)$ denotes the reflectance of the *x* point of the object. We further consider that the observer has three foreceptive fields wich sample the spectral distribution of the reflected light.

Their response, $S^x_{R,G,B}$, can be determined from the spectral distribution of the reflected light, $C^x(\lambda)$, and from the spectral senzitivity of the pigment of the fotoreceptors, $\rho_{R,G,B}(\lambda)$:

$$S^x_{R,G,B} = \int C^x(\lambda) \cdot \rho_{R,G,B}(\lambda) d(\lambda) \tag{2}$$

which is equivalent of:

$$S^x_{R,G,B} = \int E(\lambda) \cdot R^x(\lambda) \cdot \rho_{R,G,B}(\lambda) d(\lambda) \tag{3}$$

The problem of the Color Constancy appears when the spectral distribution of the ambiental light *E(λ)* is not known, and $R^x(\lambda)$, which determines the perceived color, must be estimated from the responses of the three fotoreceptors, $S^x_{R,G,B}$.

The problem was addressed by the Retinex model [1, 18] which intended to explain the human color perception and was further developed by D. Hubel [19]. The model is based upon the existance of three types of cells which could compare the activation of a certain set of cones (R,G,B) from a retina region with the medium neighborhood values, resulting a set of three values which could specify a certain color, as depicted in the upper part from Figure 1. The lower part of the image depicts an equivalent system, considered by D. Hubel to be more closed to what happens at the human cortex. According to the model, at each point of the retina one can define a specific value related to the red-green opponency (similar for yellow-blue and black-white) and the color space is fully defined using these three values.

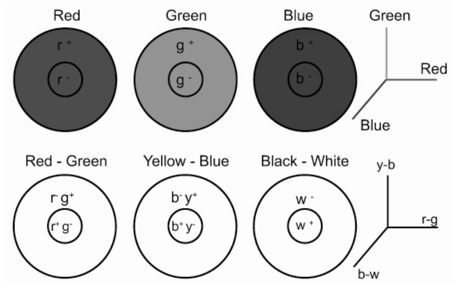

Figure 1. The Color Constancy model.

The physiological basis of this model is represented by the so called “double opponency cells”, discovered for the first time in the retina of a fish [20]. The Retinex algorithm depends on several parameters, such as threshold, number of paths, and iterations. In [21] Provenzi et. al demonstrated that the qualitative behavior of Retinex in relation to the variation of these parameters can be predicted by using only mathematical definition. They have written the basic Retinex algorithm in mathematical language, such that their definition is completely independent of the peculiarities of the implementation, and it can be used as a common background for various Retinex versions.

III. EXPERIMENTAL RESULTS

The basic Retinex algorithm was implemented using C# 3.0 for Microsoft Windows and it can process multiple formats of images (TIFF, PNG, and JPEG). The basic Retinex model is based on the assumption that the human visual system operates with three retino–cortical systems, each processing independently the low, middle, and high frequencies of the visible electromagnetic spectrum. Every independent process forms a separate image that determines a quantity *L*, called *lightness*. When Retinex is applied on digital RGB images the triplet {*LR*, *LG*, *LB*} of lightness values in the three chromatic channels is the information that determines the perception of what we call the color of a pixel of the image.

When Retinex is applied to color images, each RGB channel is processed independently to determine the lightness for each pixel by locally inspecting all nearby pixels that influence the reference pixel *i*. The formula used to compute the lightness value *L* of a pixel *i*, positioned at *(x,y)* in the image, on each of the RGB channels is:

$$L(i) = \frac{\sum_{k=1}^{N} l^{i,j_k}}{N} \tag{4}$$

A certain number of paths have been considered and the average of the norms was taken as the lightness for each pixel. Each of the paths starts at a random pixel *j* from the neighborhood of the pixels surrounding pixel *i.* The neighborhood was considered to be a rectangle of a certain dimension and the entire random path was constrained to remain all the time within the bounds of the rectangle and the margins of the image.

The norm of the path uses the ratio between the intensities of each pair of consecutive pixels. When using photos of 8-bit color depth pixels, each color channel spans over the entire [0,255] intensity interval. For technical reasons, the first value that belongs to the interval was removed to avoid division by zero, or the logarithmic scale yielding infinity. Furthermore, the intensities were normalized taking into consideration the removal of the first value. Retinex has also a reset mechanism. If, during a path computation a lighter area is found, the cumulated relative reflectance is forced to zero, making the average computation restart from this area. The effect of the reset mechanism is to consider the lightest area of an image as the white reference.

The post-Retinex processing is performed in several stages that are needed to overcome the logarithm and the normalization of the input values. Scaling to white is required because our implementation of the Retinex algorithm normalizes each of the channels to 1.

The images of mural paintings for our experiment were taken using a Nikon D7000 camera with an 18-200 Nikkor objective, fixed on a tripod. The first image was taken under poor illumination conditions, this means normal illumination conditions in a small church with small window openings, and it was followed by a set of 3 successive exposures using the Auto Exposure Bracketing (AEB) option.

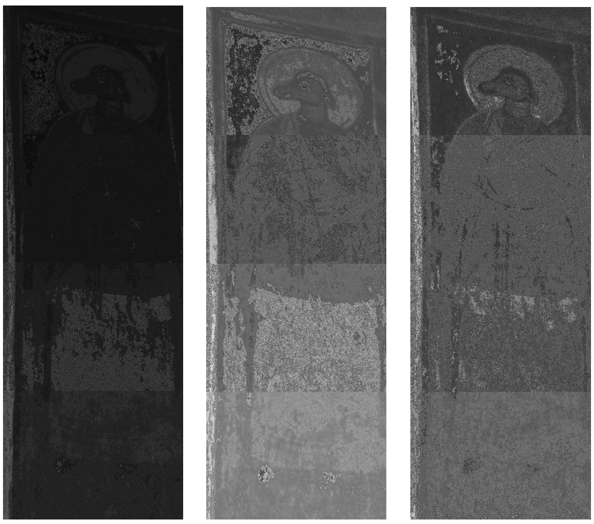

Figure 2. Test images (St. Cristofor with lamb head, mural from the old orthodox church from Râşnov). Left to right: dark image, HDRI image, Retinex processed image.

The image in figure 2, left, taken under dark luminance conditions, contains very few midtones and plentiful of shadow regions. This translates into a histogram, figure 3, up, which has a high pixel count on the far left of the plot. Due to the condition under it was taken there is not much contrast or texture to emphasize as the mid or light pixels were not recorded in the photo.

The HDRI image in figure 2, middle, is an example which contains a very broad tonal range, spanning the entire midtones region but also covering highlights and shadows. This translates into a histogram, figure 3, middle, which has a good distribution of pixel count over the entire interval, yielding a good contrast between the light and dark areas in the scene.

The Retinex algorithm that was applied on the dark image, compared to the original image is smoother in color changes and is able to create a resemblance of the HDRI image that was formed using the three successive exposures. The Retinex algorithm was able to automatically transform the initial image that contained only shadow tones to an image that contains both shadow and midtones. Contrast being a measure of the difference in brightness between light and dark areas in a scene, this algorithm was able to recover texture from an image that looked almost flat. The histograms were plotted with the Vision module of National Instrument's LabView. RGB histograms were used, for which the computer scanned through each of the RGB brightness values and counted how many pixels are at each level from 0 to 255.

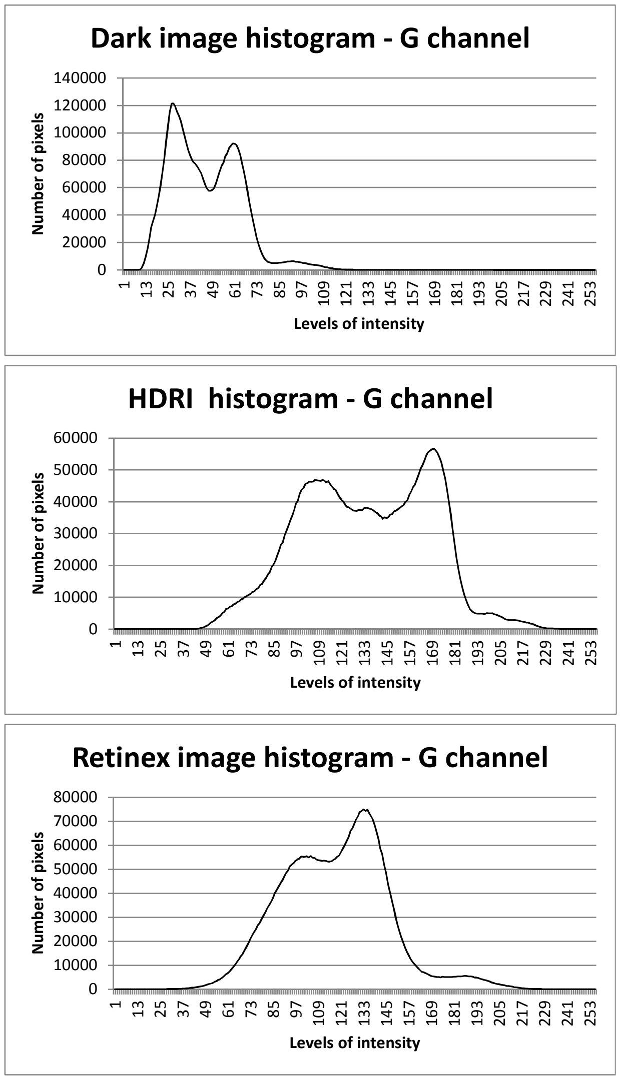

Figure 3. Histograms of the test images, green color channel only. From top to bottom: dark image, HDRI image, Retinex processed image.

The results could be better understood if we compare the above histograms with the histogram of the image which results if we apply the histogram equalization algorithm upon the first test image, showed in figure 4. The equalization of the dark image generated an image with more distinguishable textures that unfortunately has several problems, figure 4. Clipping has occurred since one can readily see the shadows and highlights pushed to the edge of the chart. Some clipping is usually acceptable in some regions, but it leads to loss of texture which is unrecoverable. The second problem is the way the equalization filter works, in that it approximates some centroids of multiple values and associates them to their representative, yielding the irregular shape of the chart. To be noticed is the "shark tooth" allure of the curves, a sign that not all tone levels are truly represented and also a sign of a “posterized” image.

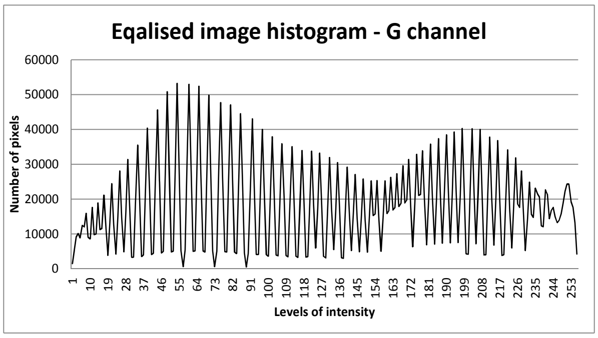

Figure 4. Histogram of the dark test image, same green color channel, after histogram equalization processing.

IV. CONCLUSIONS

The processing of mural painting images, taken under poor illumination conditions, with the Retinex algorithm elevates their quality to a higher status, with respect to the details and color, comparable with the quality of the images acquired with the HDRI technique. This is what recommends the use of the Retinex algorithm for image processing in art conservation-restoration, especially when old digital images of murals, taken in unknown or poor illumination conditions are concerned.

Images having such an important role in the documentation of conservation-restoration field, we also recommend the use of HDRI technique for digital image acquisition or postprocessing, due to the amount of details, contrast and color related information they carry within. But the use of HDRI should be accompanied by the necessary metadata, taken into consideration the long time that can pass between conservation-restoration interventions of mural paintings.

We consider that both techniques, Retinex and HDRI, should become part of the modern products, dedicated for art conservation-restoration, that are currently being developed worldwide.

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