Producing Green Computing Images to Optimize Power Consumption in OLED-based Displays

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***Abstract*—Energy consumption in Organic Light Emitting Diode (OLED) depends on the displayed contents. The power consumed by an OLED-based display is directly proportional to the luminance of the image pixels. In this paper, a novel idea is proposed to generate energy-efficient images, which consume less power when shown on an OLED-based display. The Blue color component of an image pixel is the most power-hungry i.e. it consumes more power as compared to the Red and Green color components. The main idea is to reduce the intensity of the blue color to the best possible level so that the overall power consumption is reduced while maintaining the perceptual quality of an image. The idea is inspired by the famous "Land Effect", which demonstrates that it is possible to generate a full-color image by using only two color components instead of three. experiments are performed on the Kodak image database. The results show that the proposed method is able to reduce the power consumption by 18% on average and the modified images do not lose the perceptual quality. Social media platform, where users scroll over many images, is an ideal application for the proposed method since it will greatly reduce the power consumption in mobile phones during surfing social networking applications.**

***Index Terms*—OLED Display, Green Computing, Energy-Efficient Images, Social Media, Land-Effect, Retinex Filter**

I. Introduction

With the tremendous advancement of Information Technology (IT), on one hand, the standard of life has been raised significantly, while on the other hand, the environmental issues have also arisen. IT infrastructures consume a huge amount of electricity which contributes to the greenhouse gas emission. To reduce environmental problems related to IT and to create a sustainable environment, the concept of "Green Computing" was introduced. Green IT refers to the study and practice of designing, manufacturing and using computers and other IT systems such as monitors, printers, storage devices, and networking and communication systems - efficiently and effectively with minimal or no impact on the environment [1]. Not only computers and smartphones are being designed according to Green Computing, but interestingly "Green Printing" [2] is also an addition to the "Green IT".

The power consumption is one of the major design concerns in battery-powered devices. In an electronic device, the total energy consumption depends on various hardware and software components. Screens showing the visual representation of data, known as the displays, are considered as the most power-hungry components [3], often consuming more than half of the laptop or handheld system's total energy [4].

There are typically two types of display panels used in electronic devices: (1) Liquid Crystal Display (LCD) and (2) Organic Light Emitting Diode (OLED) based displays. These display types have different operating principles and they significantly differ in power consumption characteristic. The conventional LCD systems require a constant backlight to display the images, which is the major power drainer because it is always ON even when displaying a completely dark image. On the other hand, the OLED displays do not require the backlight because its pixels are emissive. The power consumed by an OLED device when displaying a black screen is almost 0. On the other hand, images with white backgrounds, when shown on OLED-based displays, may consume more than twice the power consumed by an LCD display [5]. The pixels with different luminance and colors consume a different amount of power, hence the power consumption on such displays highly depends on the contents. This feature motivates the researchers to study and develop computationally "Green" systems to reduce the power consumption in energy-aware devices such as OLED-based displays.

A pixel is the basic unit of a digital image. Each pixel represents a different color which is a blend of three main components, the Red, the Green, and the Blue. A true color image is often known as an RGB image. Each color component of a pixel has different luminance efficacy i.e. each component differs in the ability to emit visible light using a given amount of power. Hence, there is a relation between the intensity level of RGB colors and the power consumed by an OLED device [6]. As the intensity or luminance of RGB components increases, the power consumption also increases and vice versa. Moreover, the power model described in [6] shows that the Blue pixel component is the most power-hungry color.

In this paper, a novel idea is proposed for producing energy-efficient images, which consume less power when displayed on an OLED device. The main concept is, if the intensity of the Blue color component is reduced to some extent, the power consumption can be optimized since Blue is the most power-draining color component. In order to do that, the idea of Land Effect is applied, which says that a full-color image can be obtained by using only two color components instead of three. To further enhance the image quality, the White

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Balance and the Retinex filter are applied on the images. These image enhancement operations introduce some amount of blue color component in order to improve the visual quality of images. The resulting images are comparable to the original images without losing the perceptual quality and consume significantly less power than the original images.

With the rapid increase in smartphones, the use of social networks such as Facebook and Instagram has also increased tremendously [7]. People usually spend hours and hours in scrolling down through these applications to see graphic contents - images and videos, which is the major cause of draining the battery power in smartphones. The proposed system can greatly reduce the power consumption in OLED display based smartphones. An ideal application of the proposed system is to incorporate it to social networking websites to produce energy-efficient images which will ultimately reduce the power consumption without additional CPU effort from smartphones.

The rest of the paper is organized as follows: Section II provides the background study and discusses the related work. The proposed method is described in Section III. The experimental results are shown in Section IV followed by the Conclusion in Section V.

II. Background and Related Work

The first sub-section presents the power model of an OLED display. The second sub-section discusses the related work previously done by the researchers.

A. OLED Power Model

Organic Light Emitting Diode (OLED) [8] [9] is a modern display technology which has better image quality, better horizontal and vertical view angles, and better brightness, as compared to conventional LCDs. The OLED systems comprise of an array of Light Emitting Diodes (LEDs) whose brightness depends on the image content to be displayed. The power model of an OLED display is discussed by various researchers in [6] [10] [11] [12] . The power consumed by a single pixel, represented in R, G, B form, can be modeled as shown below [6]:

$$P_{pixel} = P(R) + P(G) + P(B) \quad (1)$$

where P(R), P(G) and P(B) are the functions to compute the power consumed by red, green and blue components of a pixel. The total power consumption of an OLED display with n pixels can be modeled as follows [6]:

$$P = C + \sum_{i=1}^{n} \{P(R) + P(G) + P(B)\} \quad (2)$$

where C is a constant, which measures the constant power consumption in OLED irrespective of the displayed contents.

The linear relation between the RGB values and power consumption is shown in Fig 1 [6] [10]. It shows that the energy consumed by an OLED display is directly proportional to the luminance or intensity of red, green and blue pixel components. Moreover, it is also apparent that out of the three-pixel components, the blue color consumes almost 3 times more power as compared to the red and green color components.

In this paper, a novel idea is proposed to reduce the intensity of blue color in such a way that the perceptual quality of the original image is preserved. By doing this we ensure that the power consumption can be reduced by a noticeable amount.

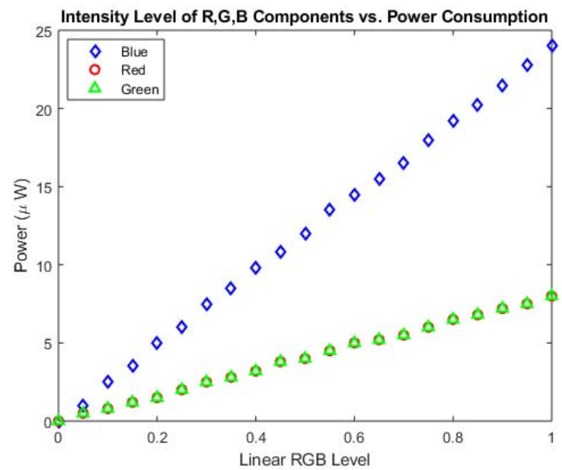


Fig. 1: Power Consumption vs. Intensity level of RGB pixel components of an OLED device [10]

B. Related Work

LCD displays require a constant backlight to show the image contents. Almost 80% of the total energy is consumed by the backlight in LCDs [13]. Extensive research have been done on LCD displays to reduce the power consumption by backlight-scaling [13] [14] [15] [16]. It is obvious that if the luminance of the backlight is reduced, the power consumption will also be reduced. But as a result of backlight dimming, the displayed image is distorted. Due to deterioration in image quality, the image enhancement techniques are applied for luminous compensation.

Apart from the overall backlight dimming, another approach of power reduction in LCDs is proposed in [17]. The authors proposed a system of continuous user monitoring by a camera. When a user distracts himself/herself from the screen, the system reduces the backlight, hence image enhancement techniques are not required because the user is not viewing the display at the time of backlight dimming. But this technique may not be suitable for privacy concerns.

However, the backlight dimming techniques cannot be applied to OLED devices because of their emissive nature. Since the power consumption in OLED based devices depends on the displayed contents, it is apparent that in order to lower the power consumption in OLED devices, the display contents should be modified in some way. Several studies have been performed to exploit the image-dependent power consumption characteristic of OLED based systems. The energy reduction for OLED display based mobile devices was pioneered by HP Labs [4] [18].

The authors in [19] proposed a *partial display dimming* system in which some selective parts of the screen, which are not important to the user, are darkened to reduce power consumption. This partial dimming technique was exploited in [20] to dim the display's top and bottom portions, because it was a common observation that a user usually focuses on half of the screen for most applications.

As discussed previously that different colors require a different amount of power, the *color remapping technique* was proposed in [21], which changes the original colors of the display to the colors which consume less power. This technique was applied to web pages rendering on mobile devices in [6]. The studies performed in [6] and [4] are targeted on Graphical User Interfaces (GUIs). The authors in [6] proposed a system for transforming GUIs in which they focused on preserving the *usability* rather than *fidelity*. Their system was based on changing the colors drastically while maintaining the distinguishability of the text from the background. Such a technique is suitable for GUIs but might not be applied to images or videos where visual image quality is a major concern. Similar consideration of *usability* is applied in [4] where power is reduced by dimming some pixels of an area of an image which is not of user interest.

OLED Dynamic Voltage Scaling (DVS) technique was introduced in [22] which retained the original visual quality of images by reducing the supply voltage of each pixel's circuit. The maximum brightness produced by the emissive devices is limited by DVS, hence image compensation is performed on each pixel. This technique requires modification in the analog hardware, thus cannot be used by off-the-shelf displays. Another hardware-assisted technique was proposed in [12] which was based on dividing an OLED display into multiple rectangular regions and optimizing the Voltage of each region to maintain the required quality. This study motivated the authors of [11] to introduce a technique called *image pixel scaling*, which aims at scaling down the pixel values in differently-shaped regions in an image. A power optimization algorithm along with limiting the image distortion was also proposed by them. All of the above-mentioned techniques were based on retaining the visual quality of images.

The attention was shifted from retaining the visual quality of an image to image contrast enhancement along with reducing the power consumption. This requires transforming an input image to an output image, represented by the following general function [23]:

$$O = T(I) \tag{3}$$

where I is an input image, $T(I)$ is a transformation function applied on the input image and O is an output image which consumes less power while improving the visual quality of the image. Non-linear optimization algorithms are used in [24] to transform the pixels that reduce the power consumption and improves color contrast. The method is effective but the optimal transformation operations are computationally expensive in this system. Another contrast enhancement combined with Histogram Shrinking (HS) technique is applied in [25] to reduce the power consumption and to obtain a visually good image. This method aims at reducing the empty bins of the image histogram and keeping the image entropy at a constant value. This technique reduces the power consumption before enhancing the image quality. Since the image contrast is not improved simultaneously, this system requires Histogram-equalization based algorithm that balance the power consumption and enhance the color contrast automatically.

An alternative way of generating "Green Images" is proposed in [26]. The authors transform an image from RGB to CIELAB color space and then exchange image colors with alternative colors which consume less power within a sphere described by them. Their results reveal that the proposed system was able to reduce the power consumption by 4.25%. This study was further extended in [10] by reducing the luminance of pixels by some threshold, reducing the overall energy consumption by 14.1%. On the other hand, the proposed system presented in this paper is able to reduce the power consumption by 18% without losing the perceptual quality of images.

III. The Proposed Method

The block diagram of the proposed system is shown in Fig 2. An input image is provided to the system, which then passes through 4 operations to get the final output image. The four operations namely, the Land Effect, White-Balance, the Retinex filter, and Adjustment of Color Intensity Level, are described in the following subsections.

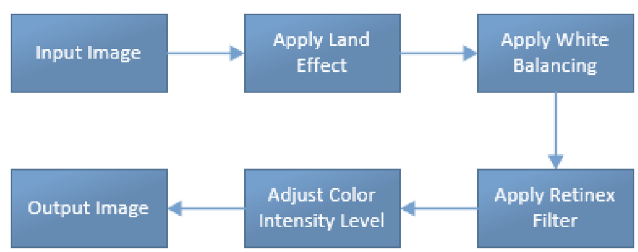


Fig. 2: Block diagram of the Proposed Method

A. *The Land Effect*

The idea proposed in this paper is inspired by the famous "Land Effect", named after its inventor Edward H. Land [27] [28]. While performing some experiments in Color Vision, Edward H. Land found that it was possible to get a full-colored image with only two color components instead of three [28]. The Land Effect was based on Human Visual Perception i.e the Human eye is capable to see a range of different colors in an image even when the actual colors are not present. It was demonstrated by the previous studies that the blue color component is the most power-hungry i.e. it consumes almost 3 times more power than the red and the green components as shown in Fig 1. At first, we took some sample images and applied the Land Effect by completely removing the Blue color component and merging the Red and Green components together. After applying the Land Effect, although all the colors were visible, but the modified images resulted in lower visual quality. Due to this reason, the other operations were performed on the images to improve the visual quality.

Fig 3 illustrates the steps involved in applying the Land Effect to the images. The first step is to decompose the original RGB image into its Red, Green and Blue color components. The next step is to superimpose a monochromatic red layer on the Red channel image and the monochromatic green layer on the Green channel image. After that reduce the opacity of the green filtered image to 24.5% and the opacity of the red filtered image to 84.5%. The red and green filtered images are then merged together; the result is a full-color image. At this stage, all the colors, including blue, are visible in the resulting image. However, the image appears to be darker and its visual quality is deteriorated as compared to the original one. We then proceed to the next operations.

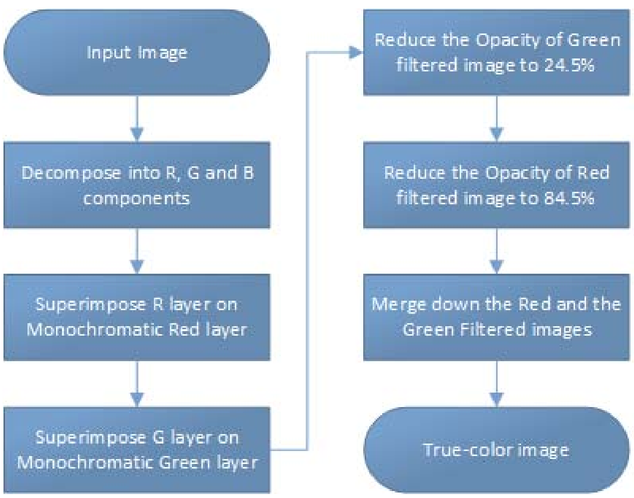


Fig. 3: Steps to apply Land Effect

B. *White Balance Operation*

The results of the Land Effect were not acceptable in terms of visual image quality. Therefore the attention was directed to enhance the modified image quality. The next step in this process is to apply the White balance operation.

Lighting conditions under which an object is viewed affect the colors of the object. White Balance is the process of removing unrealistic color casts from images so that white object appears white in an image instead of any other color. The White Balance mechanism adjusts the colors of an image by stretching the Red, Green and Blue channels separately. The pixel colors at each end of the Red, Green and Blue histograms which are only used by 0.05% of the pixels in the image are discarded [29]. Although this operation introduced small amount of blue color component in the images, but it greatly improved the visual quality of images.

C. *Retinex Filter*

The core concept of the Land Effect is that the human eye can perceive different colors even if they are not actually present in an image. The Retinex filter is actually based on Land's theory of image perception. The human eye can see the colors even when the light is low, but this is not true for a camera eye. By using the Retinex filter the visual rendering of an image can be greatly enhanced when the lighting conditions are not good.

The Retinex filter is based on the MultiScale Retinex with Color Restoration (MSRCR) algorithm, which is an automatic image enhancement algorithm that simultaneously provides dynamic range compression, color constancy and color rendition [30].

When the Retinex Filter is applied, the color constancy and contrast is enhanced and the images are rendered similarly to how human vision is believed to operate. The resulting images were enhanced in color contrast and the perceptual quality was further improved after this step.

D. *Adjustment of Color Intensity*

After applying the above three operations, the visual quality of the image was enhanced significantly. The next step is to adjust the color intensity level to reduce the luminance which will further reduce the power consumption. The purpose of this step is to try to reduce the power consumption to the best possible level without compromising on the visual quality of images.

After performing several experiments on different images, it was found that if we lower the intensity value of RGB from 1.00 to 0.72, the luminance is slightly reduced but the color contrast is greatly enhanced. The resulting images were comparable to the original images without losing the perceptual quality.

IV. Experimental Results

Experiments were carried out on the standard Kodak image database [31] to test the performance of the proposed system. The image database consists of 24 lossless true color images; each image is 768 x 512 in size.

As discussed in the previous sections, the power consumption is directly proportional to the color intensity. We calculated the difference in color intensities of the modified and the original images and measured the difference in power consumption between the original and the modified images by using the following equation:

$$\Delta P = \frac{P_1 - P_2}{P_1} * 100 \quad (4)$$

where P1 is the power consumed by the original image and P2 is the power consumed by the modified image.

Table I shows the ratio of the power consumed by the modified image to the original image for all the images present in the Kodak image database. The proposed system was able to reduce the power consumption of the modified images by 18% on an average, which can be regarded as a significant achievement. It is worth noting that of all the 24 images from the database, only 2 modified images, named "Kodim01.png" and "Kodim11.png", consumed a slightly more power than their original versions (as can be seen from Table I). The reason of this slight increase in the power consumption might be contributed to the higher brightness introduced in these images after performing the described operations.

TABLE I: Ratio of power consumed by the modified image to the original image

Image	**P2 / P1**
Kodim01.png	1.01
Kodim02.png	0.83
Kodim03.png	0.87
Kodim04.png	0.82
Kodim05.png	0.80
Kodim06.png	0.80
Kodim07.png	0.99
Kodim08.png	0.72
Kodim09.png	0.87
Kodim10.png	0.71
Kodim11.png	1.03
Kodim12.png	0.75
Kodim13.png	0.70
Kodim14.png	0.91
Kodim15.png	0.78
Kodim16.png	0.83
Kodim17.png	0.97
Kodim18.png	0.79
Kodim19.png	0.88
Kodim20.png	0.82
Kodim21.png	0.80
Kodim22.png	0.82
Kodim23.png	0.69
Kodim24.png	0.64
Mean	**18%**

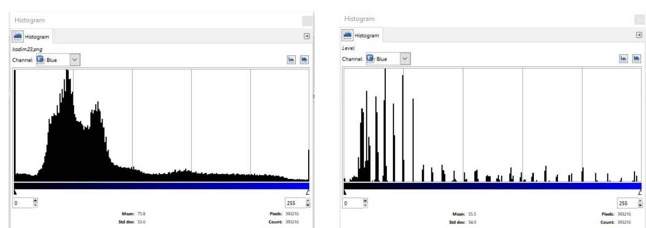
Fig 4 shows an example of an image named "Kodim23.png" from the Kodak database and the resulting image produced after applying the proposed system. Fig 4a is the original image and Fig 4b is the modified image. It can be clearly seen from the results that the modified image is better in contrast than the original image and it consumes 31% less power as compared to the original image.

(a) Original Image

(b) Modified Image

Fig. 4: Experimental Results for Kodim23.png image. The modified image consumes 31% less power than the original image.

Fig 5 compares the histograms of the blue channel of the original "Kodim23.png" image and the modified image. The histograms of the Blue color component are compared because the goal of this work was to reduce the intensity of the blue color component. It can be seen that the histogram of the original image has the Mean intensity value of 75.8, while this value is reduced to 55.5 for the modified image. The Mean value of the modified image is 26.78% less than the original image. This histogram value further confirms that the modified image has less intensity for the blue color and hence it consumes less power.

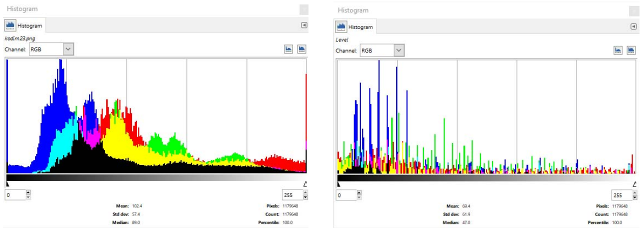


(a) Original Blue Histogram with Mean Value = 75.8

(b) Modified Blue Histogram with Mean Value = 55.5

Fig. 5: Comparison of the Blue Channel Histograms for the original and the modified image for Kodim23.png

Fig 6 compares the histograms of the RGB channel of the original "Kodim23.png" image and the modified image. It can be seen that the RGB histogram of the original image has the Mean intensity value of 102.4, while this value is reduced to 69.4 for the modified image. Hence the overall intensity of the Red, Green and Blue channels is reduced by an amount of 32.22%, thereby reducing the power consumption. Overall, the power consumption by the image named "Kodim23.png" is reduced by 31% for the modified image, while the Mean Value of Blue intensity is reduced by 26.78%.



(a) Original RGB Histogram with Mean Value = 102.4

(b) Modified RGB Histogram with Mean Value = 69.4

Fig. 6: Comparison of the RGB Channel Histograms for the original and the modified image for Kodim23.png

The experimental results demonstrated that the proposed system is able to reduce the power consumption by 18% when applied to images, without losing the visual quality.

V. Conclusion

In this paper, a novel idea was presented to modify the images in order to create energy-efficient images which consume less power as compared to the original images when displayed on energy-aware devices such as OLED displays. The modified images show a better color contrast than the original images from the visual point of view. The results demonstrate that the proposed method is able to reduce the power consumption by 18% on average without losing the perceptual quality of images. An ideal application of this approach would be to integrate this model to the Social Networking applications such as Facebook and Instagram which are the most power-draining apps due to the presence of graphics contents i.e. images and videos. Moreover, the proposed system can also be integrated to Youtube to display videos whithout consuming a huge amount of electricity. By using the proposed model, the power consumption in smartphones can be greatly reduced without losing the visual quality. The future work is to test the proposed system on more images and to perform the Subjective test in order to know the acceptance ratio of the modified images.

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