El-pincel - A Painter Cloud Service for Greener Web Pages

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ABSTRACT

Due to their thin size, vivid colors, high contrast and power efficiency, OLED (Organic Light-Emitting Diode) display and its variants such as AMOLED (Active Matrix OLED) displays are increasingly replacing traditional LCD (Liquid Crystal Display) screens in smart phones. However, the power efficiency of OLED screens greatly depends on the luminance and colors of the displayed contents on the screen. Web browsing is one of the most widely used applications in mobile devices [8]. In this paper, we present our cloud service, which intelligently re-paints the web pages in real-time with power efficient colors and HVS (Human Visual System) based tone mapping techniques, without adversely affecting the identity (brand color) of the web pages as well as the user's browsing experience. El-pincel helps to save up to 60% of OLED energy with color combinations that ensure good legibility and pleasing affective response to human eyes.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces & Presentation**]: User Interfaces; I.4.3 [**Image Processing & Computer Vision**]: Enhancement

General Terms

Algorithms, Design, Human Factors, Experimentation

Keywords

OLED display, low power, color transformation, tone mapping, cloud service, color harmony, browsing

1. INTRODUCTION

The current generation of mobile smartphones are frequently used as mobile PC replacements that can edit documents, browse the web, check emails, and play games. To enable the usage of these rich applications, smartphones are now equipped with reasonably fast CPUs, large memory, bigger displays and fast network connections. However, these capabilities come at the cost of battery lifetime as battery technologies are not growing in par with the rest of the hardware. In modern smartphones, the three main sources of power consumption are, 1) the CPU, 2) the display, and 3) the network interfaces, among which the display alone consumes more than 45% of the overall system energy [2].

Figure 1: Webpages designed using Brand Colors in their Logos

Power efficiency of OLED displays greatly depends on two parameters - the color and the luminance of the content being displayed. The higher the luminance of the content, the more power it consumes. In most OLED displays, blue color consumes more power than green or red color. In this work we present a cloud service (*El-pincel*) for web pages which exploits the properties of OLED display and characteristics of HVS, to repaint the web pages to power efficient versions for OLED based mobile devices. El-pincel is an extended version of our previous abstract paper and demonstration [1]. The cloud service handles text, background colors and images which are the most common objects in a web page. Our solution is based on the following key observations.

1. Power consumption of OLED displays depends on the luminance and color of the content [2].

2. For texts in web pages, readability and brand colors are more important than color fidelity. Most organisations have a standard color scheme for their web pages, logos, banners, etc. In this paper we call it as *brand colors*. For example, DBS bank [9] and Verizon [28] web pages primarily use a shade of Red and Black color (Figure 1). These are the main colors in their corporate logos. Our approach is based on brand color. The web pages are re-painted with respect to the brand colors of the original pages. This is in contrast to the previous works [12], where the entire web page is darkened and mapped to shades of green color. Such approaches make web pages look dark and greenish. This may bring dissatisfaction to the owners or designers of the web sites. Moreover, it won't be interesting to view all web pages in same color for the users. In addition, these approaches are browser dependent and work only for a particular browser.

3. Some browsers allow the users to define their own CSS (Cascading Style Sheet) to repaint the color of text and back-

ground layouts in a web page with a different color. However, most modern web pages utilise more than one color to display text and background. Our observations show that most of the popular webpages use two or more background colors and three or more foreground colors. By applying the user defined CSS, all the different colors will be transformed into a single color, losing the web pages' design aesthetics and color harmony.

4. For images (and videos), color fidelity is important. Hence, we cannot abruptly change the colors of these contents. We exploit HVS properties to dynamically change the colors and luminance of the images for power efficiency while preserving their visual quality. HVS properties:- 1) HVS has different sensitivity to different colors. The human eyes are more sensitive towards green than blue, therefore green appears much brighter when both colors are having the same absolute brightness [3]. The majority of the photoreceptor cones present in human eyes are sensitive to green and red, and only a few are sensitive to blue. Hence, a given pixel color can be mapped to a power efficient color that produces same level of perceived brightness. 2) HVS is more sensitive to local contrast over global contrast [21, 20]. 3) HVS has a nonlinear perceptual response to luminance [13]. For example, a source having a luminance only 18% of a reference luminance appears about half as bright [24]. The lightness perception to human eyes is roughly logarithmic. When an image is sufficiently bright, reducing some amount of brightness to the image will result in less noticeable difference as compared to reducing the same amount of brightness to a darker image.

5. The computational cost of image tone mapping in mobile clients is expensive and often results in low or negative power saving and higher latency [12]. Hence, in El-pincel, color transformations are completely done in the cloud and cached for reuse. With the exponential growth rate of smartphones, the demand for computation, storage at the server side and possibility for reuse will continueously increase.

With these insights, we devised an integrated solution which handles texts and images (adaptable to videos). We have developed novel schemes and algorithms based on the observations described above. We evaluated our approach using a combination of analytical and user testing. Our results show that we are able to save up to 60% of the display power with no perceptible loss to text readability and color harmonicity of a web page, and save up to 50% of the display power for images in a web page if the user is willing to tolerate a small amount of loss in image quality. In overall, the main contributions of this paper are as follows:

1. We present a *brand color* based novel approach for intelligently changing colors of the textual contents in a web page to power efficient colors without compromising readability.

2. We present *HVS* based novel approach for transforming images to their power efficient versions.

3. We present a *configurable cloud service* that can be configured dynamically by the user based on client's energy efficiency requirements.

4. We show that power savings can be achieved for almost all web pages. We also show that the loss of quality due to image and video transformations is kept minimum using industry standard *objective* quality metrics and *subjective* user study.

2. BACKGROUND - OLED

Organic light-emitting diode (OLED) is an emerging display technology that uses a thin film of organic compounds which emit light in response to electric current. The power consumption of OLED displays depends on the luminance and color of the content being displayed. We describe the dependencies below at higher level for easier understanding.

The organic components for each sub-pixel (red, green, blue) on the display are individually powered up to illuminate the pixels. Hence, power consumption of OLED displays depends on the luminance of the displayed content.

The OLED material used to produce blue light degrades significantly more rapidly than the materials that produce other colors. This results in a faster decrease of blue light output relative to the other colors. Manufacturers address this issue by optimising the size of the red, green and blue sub-pixels to reduce the current density through the sub-pixels, in order to equalise lifetime at full luminance [26]. This leads to an uneven power consumption by objects with different colors (while their luminance is constant). In this case, an image with a dominant blue shade consumes more power than an image with a dominant red or green shade.

3. RELATED WORK

Chuang et al. [14] proposes a color mapping algorithm that swaps current colors with an iso-lightness color set within a certain restrictions, so that the overall lightness of the final display is still the same with the original display. The original colors are significantly changed in the process and not suitable to be applied to photos and videos, in which color accuracy is important.

Dong et al. [11] describes two approaches of reducing power consumption of OLED displays through structured color transformation of standard background and foreground GUI objects, or unstructured transformation of individual pixel colors of arbitrary GUI elements. The approaches dramatically alters the original color of the displayed objects, again making it unsuitable for contents which are sensitive to color fidelity changes, such as images and videos. In their next paper [12], foreground images are simply darkened without considering HVS characteristics. Moreover, pixel-by-pixel processing is compute-intensive task.

Chulwoo et al. [18] describes a power-constrained contrast enhancement algorithm for OLED displays using log-modified histogram equalisation (LMHE) scheme, which reduces over stretching artifacts of conventional histogram equalisation technique. The algorithm is constrained by OLED power model. Their approach is more focused on contrast enhancement than power saving.

There are various works on backlight scaling for conserving display energy [17] [22] [4] [6] [5]. In all these works the content is dynamically brightened and the backlight is dimmed. A more efficient way of backlight scaling using HVS aware tone mapping is proposed by Iranli et al. [13]. However, these methods cannot be applied to OLED display which do not utilise a backlight.

4. SYSTEM DESIGN

4.1 Design Objectives

The major design objectives of our cloud service are listed below.

- Maps set of colors in a page to energy efficient colors according to user/client requirements (remaining battery level, quality requirements).
- Apply color transformation to the source file instead of the finally rendered pixels for more efficient power saving.
- Ensures readability of text, brand color identity, color fidelity of foreground images.

- Makes the solution Browser Independent. It should work seamlessly with all types of browsers.
- Introduces no additional CPU/GPU load in mobile devices, which may reduce the efficiency in power saving.

4.2 The System Components

The components of El-pincel are shown in Figure 2.

4.2.1 Client Analyzer (CA)

The Client Analyzer (CA) is the primary contact point for clients. CA gets information about a client such as device model, screen size, remaining battery power, user specified requirements (e.g. power efficiency or quality level) from the *Proxy Configurator (PC)* of the client and the HTTP requests from the browsers of the client.

Proxy Configurator (PC). Proxy configurator is a small piece of software at the client side that performs the following two tasks. 1) It configures the mobile device to use the *El-pincel* service while browsing web pages using any browser by changing the global proxy settings. 2) It collects *device specific information* (device model, remaining battery level) from the device and *user requirements (UR)* (power efficiency required, enable/disable image transformation) through user interface and transfers the data to CA. These two tasks are performed only once when the PC application is started by the user.

Communication between CA and PC. To transform the *device specific information* and *UR*, the CA do not make an explicit contact with the PC. Instead, the PC simply adds all these data in a format predefined by the CA to each web browser's proxy authentication option field. We exploit the proxy authentication service introduced in the HTTP/1.1 protocol [16] to transfer these data from mobile client to CA. When a browser makes a request to a webpage, these non-HTTP specific details are automatically added to the HTTP header by the by the browser.

The CA checks the HTTP header of each client's request packet for the *Proxy-Authorization* header field. If it does not exist, the CA sends back a *407 (Proxy Authentication Required)* response (shown in Figure 3), containing a *Proxy-Authenticate* header field, requesting for client's credentials. The client will then respond by resending the original packet with a *Proxy-Authorization* header field, containing the credentials in the form of *username:password*, encoded as Base64 string. (Note:- For the subsequent requests, the browsers will automatically add the *Proxy-Authorization* header field).

The client's *device specific information* and *user requirements* are sent through the *username* part of the credentials. The CA will decode the Base64 encoded credentials upon receiving the resent packet, and extract out these data from the *Proxy-Authorization* HTTP header of the HTTP request packet.

By exploiting proxy authentication service, we identify the client's requirement without having to implement a client-side proxy to intercept client's packets and insert custom fields to communicate with the server-side proxy. In our approach, the *Proxy Configurator (PC)* can be any Android application capable of setting proxy configurations with proxy authentication. In the current implementation, the CA expects only Device Model (DM) and UR. The UR comprises of power efficiency (percentage of power saving required) and a flag for image tone mapping.

Handling requests for HTTP pages. If a request comes from non-OLED device or unknown OLED device, the CA simply forwards the request to the source web server and simply acts as a forwarding proxy. Unknown OLED devices are those devices for which the El-pincel service do not have the *power model* in its database. If the request comes from a known OLED device, CA forwards the URL, UR and DM to *brand color manager* (described below) for further processing.

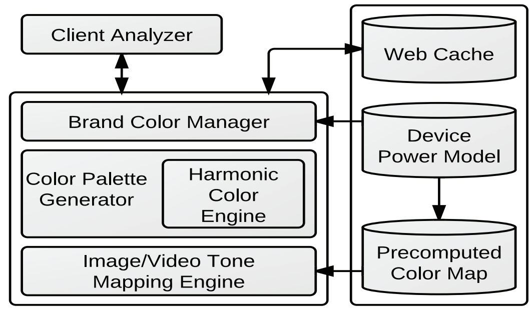


Figure 2: El-pincel Cloud System Architecture

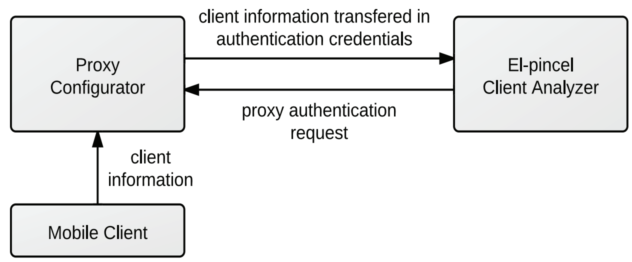


Figure 3: Client Information Transfer

4.2.2 Brand Color Manager (BCM)

Brand Color Manager gets the key image associated with the page request. The key image can be a favicon, a logo or any image with a filename *keyimage.png or keyimage.gif* located in the root of the web server. Almost all websites use *favicons* today. Favicons are usually placed in predefined URL '/favicon', which is relative to the server root. Favicons of many websites are made up of brand colors. Most of the time the favicon is simply a miniature of the company logo image. For example, Intel and our university websites use their logos as favicons (Figure 4). Hence, it is one of the useful tool to easily obtain the brand color. If favicon is not present, BCM looks for other key images. The key image is used to generate one or more base colors for the page using the *base color generation algorithm* given below. If a key image is not found, then it will default to *black* color which uses the lowest possible power.

Algorithm: Base Color Generation
Input:website URL (URL), User Requirements (UR),
Device Model (DM)

- if (cache entry exists for URL & UR & DM) then {
return the style sheet;
}
- if (cache entry does NOT exists for URL) then {
** Obtain the key image (e.g. favicon image, logo) of website;*
** Create a RGB histogram of the key image;*
** Quantise to 4096 web safe colors (256×256×256) colors;*
** Rank the colors according to their presence in key image and select the top 'n' colors; (Figure 5)*
}
- Select the specific RGB-Power model (Figure 6) for the device.
- Return 'm' power efficient colors from the 'n' colors, with power consumption of each color determined from equation (1)*;*

Power consumption of a pixel displaying color depends on the power model of the OLED display module specific to each device, and is calculated using the equation below:

$$E(C) = E_R\, r' + E_G\, g' + E_B\, b' \tag{1}$$

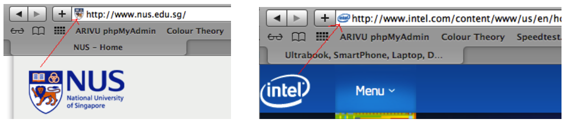


Figure 4: Logos are used as Favicons

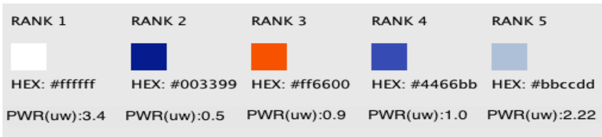


Figure 5: Color Extraction and Ranking from NUS favicon

where r', g', b' are the gamma-corrected linear RGB values of color C. E_R, E_G, and E_B are constants that varies with different OLED displays [10], and are determined from the device-specific power model in Figure 6.

Figure 5 shows the top *n* colors picked from favicon of our university website. The colors are ranked according to their presence in the logo. Total number of pixels in the image representing a color determines the presence of the color in the image. A color with higher presence gets higher rank. The power required in $\mu Watt$ to display one pixel in the selected color with respect to the power model in Figure 6 is also shown in the image.

4.2.3 Color Palette Generator

The Color Palette Generator selects a color from 'm' base colors based on the requirements from client (e.g. level of power saving required). Then, using the color wheel [7] depicted in Figure 7 it selects set of *monochromatic* (from types I,V,T) and *complementary* colors (from types I, Y, X) for the color palette. From these colors a set of monochromatic and complementary colors which are harmonic to each other are selected by the **Harmonic Color Engine**. From the selected set, the monochromatic colors are used as background colors and the complementary colors are used as foreground colors to ensure sufficient *chromatic contrast*. These colors are used to generate new CSS after assuring W3C recommended [25] amount of *achromatic contrast* (or brightness difference) between them for good legibility. W3C recommends minimum 125 units of brightness difference between two colors for good color visibility. Color brightness is determined by:

$$Br = 0.299\, r' + 0.587\, g' + 0.114\, b' \qquad (2)$$

where, Br is brightness and r', g' and b' are gamma corrected values of the red, green and blue sub pixels.

Note: W3C takes this equation from a formula for converting RGB values to YIQ values. This brightness value gives a perceived brightness for a color.

4.2.4 Image Tone Mapping Engine

The image tone mapping engine converts all images to power efficient version based on the client requirements. We devised a HVS based approach to convert the images without distorting the visual quality. The details are described in Section 4.3.

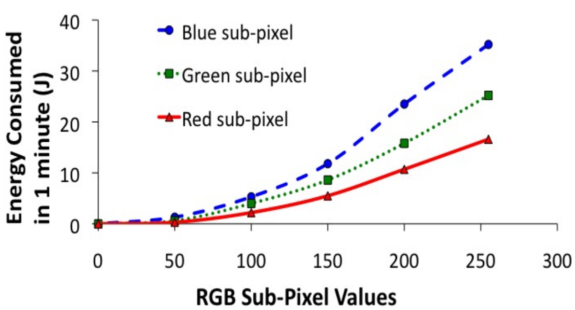


Figure 6: RGB Pixels Power Model(Google Nexus One OLED display)

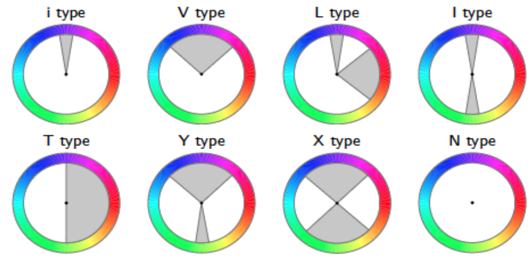


Figure 7: Color (Hue) Wheel Types

4.2.5 Web Cache

Most of the current research works on mobile energy management are focused on saving energy in the mobile client alone for longer battery lifetime. Saving energy on one computer causes another to consume more energy, increasing overall carbon emissions [19]. El-pincel stores the processed CSS stylesheets and images of popular (top *n*) sites in cache for future retrieval by the same user or new users. This key component saves power at the server side, reducing overall energy consumption of the whole system instead of simply mitigating the required energy consumption to the server side. We cache different versions of modified pages for each device model and each power efficiency requirement. To minimise the cache size, the power efficiency requirements are discretised into 16 levels in multiples of 5%. That is, 5%, 10%, 15% .... 80% power saving levels. For instance, if *n* is 20, the cache will have data for *10 x 16 x number of device models* which is a manageable size for cloud storage. The cache is updated with HTTP *Conditional-GET* whenever a request comes for a page.

4.3 Basic Approaches for Image Tone Mapping

There are a few basic approaches to generate energy efficient images:

Approach 1 - Simple Darkening: Darken the image to appropriate levels. By decreasing the RGB sub-pixel values of each pixel uniformly by a constant value, the brightness, *Br* can be reduced (3). Such naive approaches result in degradation of the content (image or video frame) quality. If the image is already dark, a large number of pixels will saturate resulting in a flat image with loss of contrast compared to the original image (Figure 8).

$$Br_{reduced} = Br_{original} - x \qquad (3)$$

Approach 2 - Relative Darkening Alternatively, the brightness of each pixel can be reduced by a certain percentage to avoid saturation (4). For example, 10% brightness reduction on a sub-pixel with a value of 200 will reduce the value to 180, whereas if the sub-pixel value is 10, it will be reduced to 9. However, this results in the compression of the color histogram, which results in greater contrast loss (Figure 8).

$$Br_{reduced} = Br_{original} \times y\% \qquad (4)$$

4.4 HVS based Tone Mapping for Images

4.4.1 Overview

As discussed in section 3, simple color mapping approach is not applicable for images where it is important to preserve color hue. Also, reducing brightness of an image results in contrast loss, although HVS is more sensitive to local contrast than global contrast.

Figure 8: Effects of basic approaches on Image Contrast

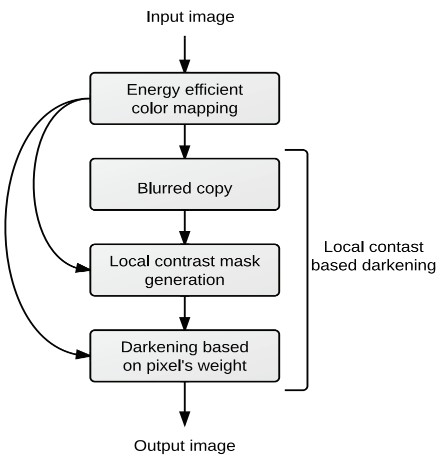


Figure 9: Image Transformation Flowchart

We have devised an algorithm (Figure 9) that transforms an image so that the power saving can be approximated to the required level. This is achieved by distributing the exact required power saving to each pixel of the image.

Instead of simple color mapping, we apply *energy efficient color mapping* that is constrained by luminance, hue and saturation of the original colors. Luminance between original and mapped color is maintained in this step. To retain the local contrast, we generate a local contrast mask that applies less weight on area with higher local contrast, which is approximated by detecting edges in an image. Using *local contrast based darkening* technique, area with higher weight values (lower local contrast) will experience higher drop in luminance to achieve power saving.

4.4.2 Energy Efficient Color Mapping

Given a power model for an OLED display, a one to one mapping from the original color to energy efficient color is generated. This is an offline process in which the mapping is computed once for each power model and stored in the El-pincel database. The mapping for each color is decided by solving an optimisation problem as follows.

For each color C_0, we want to map it to a $C' = (r', g', b')$ with minimum power consumption subjected to some constraints on the differences between C' and C_0. Specifically, given $C_0 = (r_0, g_0, b_0)$ we want to

$$\begin{aligned} \text{minimise} \quad & E(C') \\ \text{subject to} \quad & L(C') \geq L(C_0) \\ & |H(C') - H(C_0)| \leq a \\ & (1-b)\cdot S(C_0) \leq S(C') \leq (1+b)\cdot S(C_0) \end{aligned}$$

where a, b are configurable parameters that controls the strictness of the constraints. In our implementation, $a = 9$ and $b = 0.25$ provides the optimal balance between power saving and image distortion.

The function to minimise is the power consumption (in microwatts) of the pixel displaying the color, determined from equation (1).

Luminance, L(C) is the perceived brightness of color C derived from equation (2).

$H(C)$ and $S(C)$ is based on the hue and saturation component of the HSV color space.

Hue, $H(C)$, measures the similarity of color C to well described color such as red, green and blue.

$$H(C) = \text{atan2}(\sqrt{3}\cdot(g-b), 2\cdot(r-g-b)) \tag{5}$$

Saturation, $S(C)$, describes the colorfulness of color C from grayscale to pure color.

$$S(C) = \frac{\max(r,g,b) - \min(r,g,b)}{\max(r,g,b)} \tag{6}$$

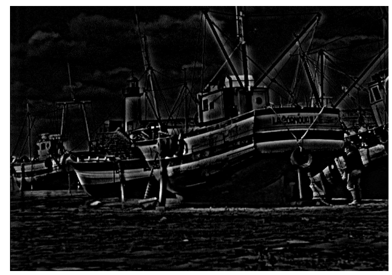


Figure 10: Local Contrast Mask

4.4.3 Local Contrast Based Darkening

The energy efficient color mapped (EECM) image is passed through a Gaussian blur filter with a suitable blur radius. Each pixel value of the blurred copy is then subtracted from the corresponding pixel value of the EECM image to generate the local contrast mask (Figure 10). The local contrast mask acts as a weight map for pixel darkening with each value in the weight map corresponds to a weight, $W(x)$ to determine the intensity of darkening for pixel x.

The weight is further adjusted for each pixel x based on current power consumption of the pixel. The more power the pixel consumes, the higher is the adjusted weight.

$$W'(x) = W(x)\cdot\frac{P(x)}{\sum_{n=0}^{N} P_{max}(x)} \tag{7}$$

$P_{max}(x)$ is the maximum power consumption of a pixel in the current power model.

Target power saving of each pixel, S_x is then distributed based on each pixel's adjusted weight $W'(x)$.

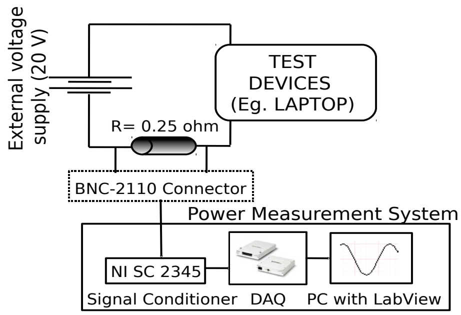


Figure 11: Power Measurement Setup

$$S_x = P_T \cdot \frac{W'(x)}{\sum_{n=0}^{N} W'(n)} \tag{8}$$

where P_T is the total desired power saving.

Finally, the original *RGB* values for each pixel x will be reduced according to assigned target power saving, S_x to get final $R'G'B'$ values:

$$R' = R \cdot d, \quad G' = G \cdot d, \quad B' = B \cdot d \tag{9}$$

with d determines the percentage drop in RGB value for pixel x corresponding to S_x target power saving.

5. EVALUATION & RESULTS

In this section, we present our evaluation methodology and the results. Our goal was to find the amount of power saved by our system and its impact on the quality of the content.

To calculate the amount of power saved, we measured the power consumed by the original and modified content. These results are presented in Section 5.2. We present the objective evaluation using the metrics - Chromatic Contrast (CC) and Achromatic Contrast (ACC) for texts to show that our system follows W3C recommendations and hence it is legible. We use industry standard metrics - Global Contrast Loss (GCL) and Structural Similarity Index (SSIM) for images to show that our approach retains the quality of the content to be close to the original content. We have also conducted two user studies to compare the original and modified contents. The results are presented in Section 5.2.

5.1 Evaluation Methodology

5.1.1 Power Measurements

We performed our power measurements on a Google Nexus One phone using Power Tutor software [27], and arrived at the power model shown in Figure 6. The graph gives the power consumption of a pixel for red, green and blue components. We have used these values to compute precisely the power consumption of original and modified contents. Hence, the results here are based on the OLED screen in Google Nexus One smart phone. However, for most of the phones the blue pixels consume approximately two times the power of red and blue pixel. Hence, it can be easily genralised for most other OLED smartphones.

To measure the current consumption of the cloud service, we run El-pincel in a *Lenovo W500 laptop* and measured the current consumption by removing the battery and then intercepting the power intake. The current consumed (in Amps) was measured using a Data Acquisition (DAQ) device as shown in Figure 11, for a period of over one minute with the voltage set at 20V.

5.1.2 Communication Cost

Due to additional processing and communication, El-pincel introduces the following communication costs: 1) additional communication latency for routing packets through El-pencil, 2) processing latency for color transformation and 3) additional bandwidth. We have written a small script in Java to measure the time between requesting for an object and receiving it at the client side. We measured the processing latency by recording the time taken for image and CSS color transformation. El-pincel do not introduce any additional communication at the client side. With El-pincel, the number of messages sent and received by a client do not change except for *Proxy-Authorization* information exchange which is performed once when the client connects to the El-pincel service. However, it is important that the cloud service hosting El-pincel must be scalable and be provided with sufficient bandwidth to support all client requests.

5.1.3 Quality Measurements - Objective Metrics

Chromatic Contrast (CC) (Difference in Hue) and Achromatic Contrast (ACC) (or Color Brightness Difference) are used for texts to ensure legibility. Traditional metrics for image quality measurement such as Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) tend to ignore the attributes of HVS perception. As described above, HVS has different levels of sensitivity to different colors and different luminance levels. Hence, we used Global Contrast Loss (GCL) and Structural Similarity Index (SSIM) for images. We define *global contrast* as the standard deviation among all the pixel values in the image. A low contrast results in the image appearing "washed out" as all the pixels look similar. For example, if the image is more or less flat (pixel values are close to each other), saturating x% of pixels makes the image complete black. We define GCL as the difference (loss) in global contrast between the modified and original content.

To account for HVS, we used SSIM, a more complex metric which accounts for human perception, and is gaining increasing popularity among the image processing community.

The principle philosophy underlying the SSIM approach is that HVS is highly adapted to extract structural information from visual scenes. In particular, images are highly structured and these structures are important cues about perceived image quality. To account for this property, SSIM breaks an image into patches and compares the quality of each patch with other patches using three attributes of quality; namely luminance, contrast and structural similarity.

Let x be the pixel array of the patch from the original image and y be the pixel array of the patch from the modified image. The SSIM Index between these two patches, SSIM(x,y) is defined in Equation 10. The index ranges from -1 to +1, with -1 representing high distortion and +1 representing low distortion (high quality). The SSIM index will be +1 when a patch is compared with itself.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{10}$$

where,

- μ_x, μ_y the average of x, y;
- σ_x^2, σ_y^2 the variance of x, y;
- σ_{xy} the covariance of x and y;
- $c_1 = (k_1L)^2$, $c_2 = (k_2L)^2$ two variables to stabilise the division with weak denominator;
- L the dynamic range of the pixel-values (typically, this is $2^{no.of bits\ per\ pixel} - 1$);
- $k_1 = 0.01$ and $k_2 = 0.03$ by default. These values are obtained through experiments [29].

In this paper, we are interested in comparing two complete images. Hence we use the *Mean SSIM* (MSSIM) value, shown in

Equation 11, that averages the SSIM values of all the patch comparisons. More detailed explanation of the SSIM, including its complex mathematical derivation and improvements over the existing approaches is available elsewhere [29].

$$MSSIM(x,y) = \frac{1}{N}\sum_{j=1}^{N} SSIM(x_j, y_j) \qquad (11)$$

where N is the number of patches or windows.

5.1.4 Quality Measurements - Subjective User Study

As our content transformation techniques are HVS based, the study on the perceived quality with actual human subjects is essential to validate the approach. We did two user studies with 65 student users with different backgrounds. As our service is developed for mobile devices, we let the users view the original and modified contents over the WWW (accessible by any internet connected devices including smartphones) in various lighting conditions (e.g. office, outdoor, day/night) to validate the practical usability of our service. The user demography is shown in Table 1.

Total Number	65 (in age group 19-35)
Gender	Male (55), Female(10)
Photography Experience	Beginner (30), Amateur (27), Semi-professional (6), Professional (2)
Photo Editing Tool	Photoshop (37), Paintshop Pro (2), others (40). [some use morethan 1]
Web Development Experience	Beginner (29), Amateur (24), Semi-professional (11), Professional (1)
Web surfing per day using smartphones/tabs	Never (15), 1-5 Hrs (43), 5-10 Hrs(5), morethan 10 hrs(2)

Table 1: Demographics Statistics for the User Study

Our first user study compares the original and the modified versions of web pages for various energy efficiency settings. The users were asked to rank the readability of the text with 3-point Likert Scale, where 1 indicates *hard to read*, 2 indicates *readable with some efforts* and 3 indicates *clearly readable*. The users also ranked harmonicity of the colors of the page contents with 3-point Likert Scale, where 1 indicates *not harmonious*, 2 indicates *somewhat harmonious* and 3 indicates *harmonious*. Each user was presented with 20 web pages from a pool of original, 20%, 40%, 60% and 80% power saving versions of the web pages.

Our second user study compares our image manipulation technique with the basic approaches. We gave a pair of images from a pool of original, 20%, 40%, 60% and 80% power saving versions of images generated using simple darkening, relative darkening and our HVS based approach. We presented 40 image pairs in random order to the users. The users were asked to select the most visually appealing image in each pair.

5.2 Evaluation Results

The results of accessing web pages on a Google Nexus One smart phone with and without the cloud service are given in Figure 12. The results are shown for saving around 20%, 40% and 60% power. The power saving level is a user selectable parameter in the cloud service. The chromatic contrast of the texts in original pages are 700-800 and that of the modified pages are 650-700. The achromatic contrast (brightness contrast) are 200-250 and 175-220 for original and modified pages respectively. W3C recommended values for minimum chromatic and a chromatic contrast are 500 and 125 respectively [25]. The transformed pages maintain this

Figure 12: Web Page Transformation with El-pincel

requirement while saving required amount of display power. In addition, the colors of a transformed page are harmonious to each other irrespective of the amount of power saved. The pixel by pixel darkening and greening approaches for GUI objects and Texts in previous works [12] do not guarantee harmonicity and contrast (chromatic and achromatic) requirements for comfortable reading. Moreover, as shown in Figure 13 they do not retain brand identity. ESPN brand colors are red, white and black.

We have used a mixed set of popular and unpopular websites for the user study. They are *wordpress.com*, *apple.com*, *netlingo.com*, *foohack.com*. *anuflora.com* and *clickbank.com*. We have selected the pages with less Flash contents as the service is yet to evolve to handle Flash. After removing six invalid users (selected same option for all) with biased entries, the final results are presented in Figure 14. The score is the sum of the Likert scale options (3, 2 or 1) selected by users, where 3 is the best quality. The pages are displayed in random. For up to 60% energy saving, the transformation provides good legibility and harmonicity score close to or higher than the original version while up to 80% is acceptable for most users.

5.2.1 Evaluation results of HVS based Image Manipulation

We have selected a random set of six images from Kodak test image database [15] for evaluation. For objective analysis we have

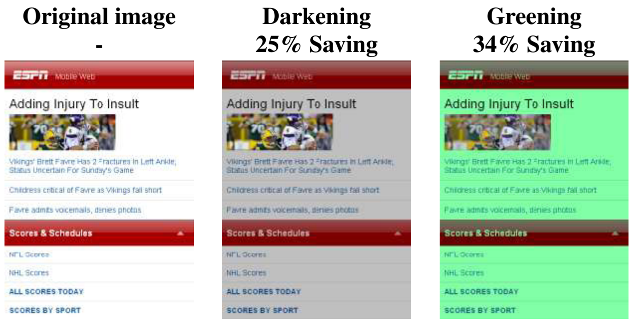
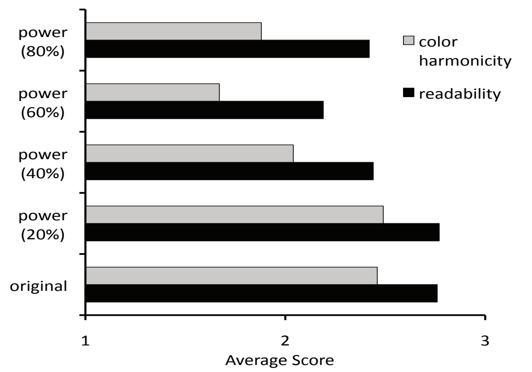


Figure 13: Previous Works - GUI and Texts [12]



Scores for Readability: 1 - *hard to read*, 2 - *readable with some efforts* and 3 - *clearly readable*.
Scores for Harmonicity: 1 - *not harmonious*, 2 - i *somewhat harmonious* and 3 - *harmonious*.
power(xx%) - is the amount of power saved by the transformed page.

Figure 14: Web Page Transformation - User Study

applied all these approaches on the original images while keeping constant power saving. Power and quality measurement for all the three images (out of six due to space constraint) and their power optimised versions are shown in Figure 15. All approaches are calibrated to consume roughly same amount of power. As expected the simple darkening approach provides lower GCL. However, it experiences lower PSNR and MSSIM. The relative darkening approach gives better MSSIM while its GCL is high making the images flat. Our approach performs better in both the parameters and ensures better visual quality.

The user study shows mixed results. The results after removing biased entries are shown in Figure 16. Normalised performance count is a ratio between total number of times the image appeared in the pair for selection and number of times it is selected as the best. For high power saving, HVS outperforms other and for low power saving, simple darkening approach performs better. This may be due to its capability to retain global contrast when minimal changes are made. Hence, we planed to deploy a power level adaptive approach for our cloud service.

5.2.2 *Communication and Processing Cost*

The costs were measured while the service is running as a personal cloud service in a *DELL Power Edge T610 Tower Server* with a hexa-core processor, 24GB RAM and 1 TB HDD. We have disabled the cache to get the actual end-to-end latency. El-pincel introduces an additional latency of 250 ms on average between requesting and receiving an image object from a client over a 3G-WCDMA 7.2 Mbps network. For CSS files (for text color transformation), it introduces an average additional latency of 175 ms. For other files, it is about 90 ms. The latency for images and CSS files also

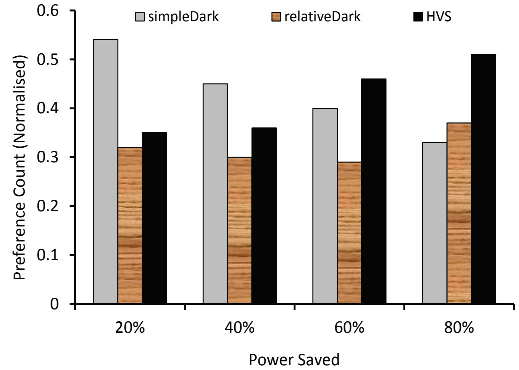


Figure 16: Image Transformation - User Study

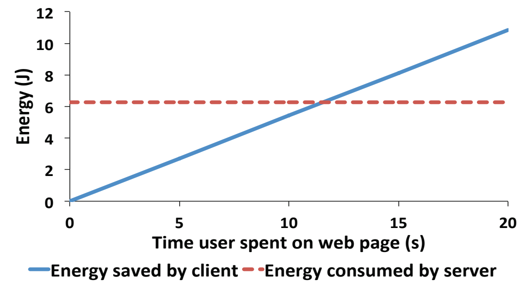


Figure 17: Break-even point between Client Energy Saving and Server Energy Consumption

includes the processing latency (for color transformation) at the El-pincel server, which is less than 100 ms for images and CSS files. However, when objects are retrieved in parallel, the net delay per object is much lower. These latencies can be further reduced with better implementation (optimising the code) of our approach.

5.2.3 *Energy Cost*

Overall energy efficiency increases when the duration a user spends in reading a power efficient page increases, as there will be a break-even point where the energy saved on client side offsets the energy spent on the cloud for processing and transforming the web pages. This is illustrated in Figure 17. We measured the energy consumption of displaying the home page of *amazon.com* at 50% display power saving on both client and server. Energy consumption on server side is constant because the server is not doing any work once the page is processed and transferred to client. The idle energy consumption of server is not considered as it is negligible as the cloud service scales in size.

From our experiment, the break-even point occurs after 11.5 seconds are spent by user on the web page. Beyond this time, there is a positive net saving of energy. The break-even point differs for different web pages and different amount of required power saving, but our experiment shows that it is reasonably within the time period a person would normally spent on a web page.

5.2.4 *Overall Result: System Works Very Well*

We now combine the results of both text and image transformations. The trade-offs involved in saving OLED display power are when high energy saving is required, it is clear that the key image based text/background color transformation approach should be combined with HVS based image transformation approach to save 60% (and above) power while providing best possible quality. With this combination, the users experienced an additional latency of 2-5 seconds in getting the contents through the cloud for up to 65 users accessing the service concurrently. For saving power up

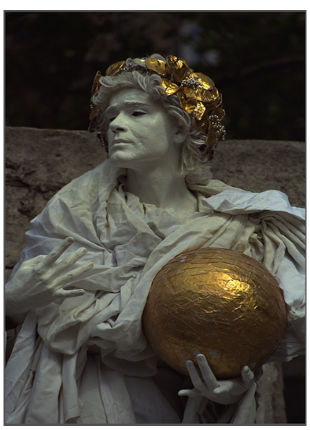
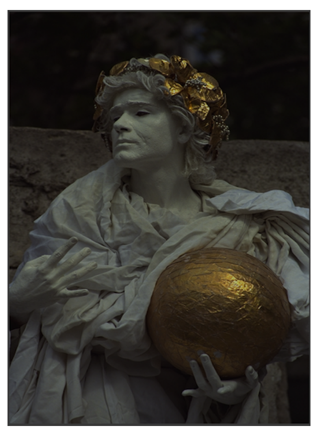
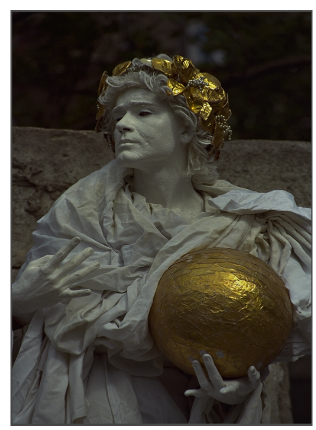
Original image	**Simple darkening approach**	**Relative darkening approach**	**Our approach**
			
Power: 494.0 mW GCL: 0 PSNR: ∞ dB MSSIM: 1.000	Power: 245.7 mW GCL: 0.5 PSNR: 14.731 dB MSSIM: 0.902	Power: 246.2 mW GCL:12.3 PSNR: 15.219 dB MSSIM: 0.932	Power: 245.3 mW GCL: 10.0 PSNR: 15.185 dB MSSIM: 0.942
			
Power: 256.1 mW GCL: 0 PSNR: ∞ dB MSSIM: 1.000	Power: 127.7 mW GCL: 0.3 PSNR: 16.143 dB MSSIM: 0.810	Power: 127.2 mW GCL: 14.4 PSNR: 17.921 dB MSSIM: 0.921	Power: 127.1 mW GCL: 12.5 PSNR: 17.781 dB MSSIM: 0.928
			
Power: 142.2 mW GCL: 0 PSNR: ∞ dB MSSIM: 1.000	Power: 71.1 mW GCL: 4.3 PSNR: 18.826 dB MSSIM: 0.664	Power: 71.1 mW GCL: 12.9 PSNR: 20.359 dB MSSIM: 0.926	Power: 71.1 mW GCL: 12.9 PSNR: 20.232 dB MSSIM: 0.940

Figure 15: Power Consumption and Quality Measurements

to 50% it is recommended to use simple darkening approach with text transformation. With this combination, the user experienced less than 2 seconds additional latency, as the processing latency for simple darkening is very low. To support large number of users, existing powerful clouds with cluster of servers can be used.

6. DISCUSSION & FUTURE WORK

We presented the web content transformation techniques and the possibility of running it as a cloud service. However, we did not focus on the resource requirements at the cloud. We assumed infinite amount of resources (perfect scalability) in the cloud and did not study the performance issues such as, cache efficiency (cache hit rates) and cloud load balancing. We defer this to future work.

We plan to study the effect of our algorithms on other contents such as flash contents, videos and animations in the future. For live video streaming, performance is critical. As the average changes between the successive frames in a typical video are minimum, we can store the computed contrast mask values of current frame and apply the same values to the successive frames which are similar to the current frame. Such data are easily obtainable in widely used video streaming formats such as MPEG-2. MPEG-2 stores video frames in GOP (group of pictures) structure, where each GOP contains an I frame and a set of P and/or B frames [23].

7. CONCLUSION

We have presented our cloud service which repaints the web texts with power efficient colors while ensuring the legibility and brand color identity. Our service intelligently exploits the properties of HVS to transform images and videos into power efficient versions while ensuring the color fidelity. We have evaluated our approach with both objective and subjective metrics. With our service the mobile phone users can save up to 60% of energy with acceptable quality levels while browsing web pages. As display is the dominant power consuming component, this translates to about 28% of overall system power saving.

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