Lab 2 - Energy-Efficient Image Processing

1. Objective

The lab demonstrates how image manipulation can be used to tradeoff image quality to save power in emissive displays.

Day 1	Estimate power consumption in OLED displays
	Estimate distortion between two images
	Experiment the impact of simple transformations on power and distortion
Day 2	Experiment with Dynamic Voltage Scaling applied to OLEDs
	Test the impact of image compensation techniques on the visual quality obtained after DVS

2. Day 1

Goal: learn to manipulate images in MATLAB and study the effect of image manipulations on power consumption and image distortion.

a) Identification of images

Test images for the evaluation will be:

- The 44 images included in the USC SIPI Database.
  http://sipi.usc.edu/database/database.php?volume=misc
- The 200 training images from the BSDS500 Database.
  http://www.eecs.berkeley.edu/Research/Projects/CS/vision/grouping/BSR/BSR_bsds500.tgz (images are found under "BSR/BSDS500/data/images/train")
- 5 images representing different screenshots of your computer
  (use images that differ significantly!)

b) Manipulation of images

For this step select one test image to experiment the flow. Basic steps include:

- Import the image (check `imread()` function for supported formats)
- Extract R, G, B channels
- Convert between different color spaces

NOTE: Please refer http://www.mathworks.it/help/toolbox/images/

c) Evaluation of power consumption

Define a MATLAB function that estimates the power of an image. Power of a single pixel for a specific OLED display is given by the following equation:

$$P(R,G,B) = w_R * R^{\gamma} + w_G * G^{\gamma} + w_B * B^{\gamma}$$

Where:

- $w_R = 2.13636845*10^{-7}$
- $w_G = 1.77746705*10^{-7}$
- $w_B = 2.14348309*10^{-7}$
- $\gamma = 0.7755$

and R,G,B are the intensities of the color channels (between 0 and 255). The power of the entire image is obtained by summing the power value of each pixel plus the baseline power $w_0 = 1.48169521*10^{-6}$:

$$\mathbf{P_{image} = w_0 + \Sigma_{i=1...N}\, Pi(R,G,B) \quad [W]}$$

Where N is the number of pixels of the image.

d) Evaluation of image distortion

Define a MATLAB function that evaluates the distortion w.r.t. the original image. Use two different metrics of distortion:

1) The sum (over all pixels) of the Euclidean distance between corresponding pixels in the in L*a*b* space, that is:

$$\boldsymbol{\varepsilon(image_i, image_j) = \Sigma_{k=1...N}\, (sqrt((L_{i,k}-L_{j,k})^2+(a_{i,k}-a_{j,k})^2+(b_{i,k}-b_{j,k})^2)}$$

Where subscript i and j refer to the two images and k denotes the k-th pixel of the image. To convert RGB into Lab space (and vice versa) use the built-in MATLAB functions `rgb2lab()` and `rgb2lab()`).

2) The Mean Structural Similarity Index (MSSIM), a complex metric considering brightness, contrast and structure differences. Use the built-in MATLAB function `ssim()` to compute it.

Compare the two metrics and analyze which one correlates better with visual similarities (looking at *some* of the images, as an example).

e) Assignment: Evaluation of various strategies on image modification

Experiment with the following image manipulation strategies and analyze their impact on power consumption and distortion using the original image as reference. Basic set of techniques to demonstrate:

- Simple pixel-wise transformations (e.g., reduce the hungry blue component by subtracting some fixed value to the blue channel)
- Histogram equalization.
- Other brightness/contrast modifications (**use your imagination**, some ideas: combinations of the previous transformations, polynomial transformations, histogram equalization applied selectively depending on the image, etc.)

Find the best possible image manipulation method to minimize the power consumption while limiting the average image distortion within the given average relative distortion values (1%, 5%, 10%), as follows:

1) When using the distance in L*a*b space as a distortion metric, the relative distortion in percentage between two images is computed as:

$$\varepsilon\ (\text{image}_{\text{original}}, \text{image}_{\text{result}})\ /\ \varepsilon\ (\text{white, black}) * 100\ (\%)$$

2) When using the MSSIM as a distortion metric, the relative distortion in percentage between two images is simply:

$$\text{MSSIM}(\text{image}_{\text{original}}, \text{image}_{\text{result}}) * 100\ (\%)$$

Notice that histogram equalization is not a pixel-based transformation. Moreover, histogram equalization and other brightness/contrast modifications require conversion of RGB into another color space such as HSV (see material on the web).

Please apply the implemented methods *on the entire image set* by organizing everything into a script so that you can automatically test and evaluate all images at once.

3. Day 2

Goal: experiment with Dynamic Voltage Scaling (DVS) applied to OLED displays. Test the impact of different supply voltages on image quality and the effectiveness of different image compensation techniques.

f) **Power consumption of OLED display with Voltage scaling**
We use here a different power model based on the current and driver supply voltage provided to a cell.

- **Cell current calculation**
Calculate the R, G, B cell current to illuminate the cell for given color values. Input and output format are 3*W*H matrix where W and H are horizontal and vertical resolution of the image (in pixels). The current of single cell is empirically given by the following equation:

$$I_{cell} = (p_1\ V_{DD}\ D_{RGB} / 255) + (p_2\ D_{RGB} / 255) + p_3 \qquad [\text{mA}]$$

where p_1 = 4.251e-05, p_2 = -3.029e-04, p_3 = 3.024e-05, and default V_{DD} = 15V. $\mathbf{D_{RGB}}$ represents color value for R,G, and B in 8 bits respectively.

Then, the power consumption of display panel is given by:

$$P_{panel} = V_{DD} \Sigma_{i=1\ldots W} \Sigma_{j=1\ldots H} I_{cell,\,i,j} \qquad [mW]$$

- **`RGB_image = Displayed_image(`I_{cell}`, `V_{DD}`, mode)`**
  MATLAB function to display the image with given image and V_{DD} on the target panel model Input and output format are 3*W*H matrix of cell current and image in RGB format. Try to run **`example.m`** in the test code.

g) Assignment: Supply voltage scaling and image compensation
Please implement the following methods in MATLAB:
- Brightness compensation (as defined in class)
- Contrast enhancement (as defined in class)
- Concurrent brightness compensation and contrast enhancement (as defined in class)

Find optimal supply voltage and compensated image to minimize the power consumption while limiting the average image distortion within the given average relative distortion values (1%, 5%, 10%).

Please apply the implemented methods on the entire image set by organizing everything into a script so that you can automatically test and evaluate all images at once.

4. Organization, Deadlines, and Evaluation

This lab accounts for 2 points overall. You will have to deliver a short (4-5 pages plus plots/tables etc.) document including:
- The outcome of the experimentation of points a) to d) and f)
- The description of the results relative to point e) and g)

You should also deliver all the **modified code** useful to reproduce your results.