POLITECNICO DI TORINO

Master's Degree in Computer Engineering

Energy Management for IoT

Lab 2 Report

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1. Image Manipulation

The main goal of this laboratory section is to demonstrate how image manipulation can be used in Organic Light-Emitting Diode (OLED) displays as a mean of reducing power consumption. The scripts *main1.m* applies different techniques over the extracted image-set, evaluating the trade-off between power consumption and image distortion.

1.1. Color Reduction

The first transformation evaluated consisted of a simple pixel-wise color reduction implemented by the MATLAB function *color_manipulation.m*, subtracting a fixed value to the power-hungry red and blue channels. The image in Fig. 1.1 has a particularly large power consumption due to its prevalence of red and blue colors. Notice the substantial MSSIM decrease with a color reduction higher than 15%. Indeed, the image starts to become greenish, since the green channel remains unchanged. Reduction rates higher than 25% yield poor-quality images, therefore, they were neglected during the experiments.

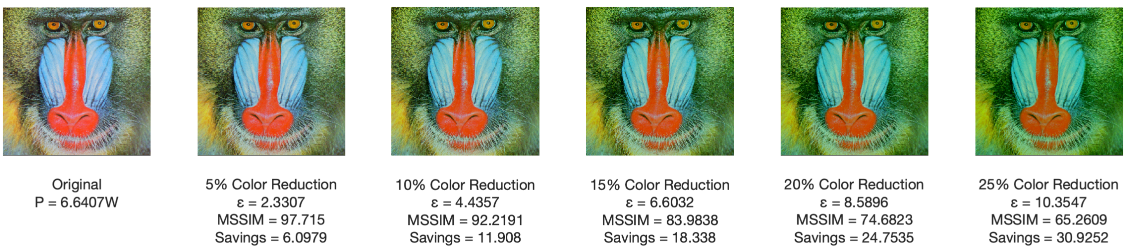


Figure 1.1: Example of color reduction.

1.2. Histogram Equalization

Histogram equalization is a transformation that adjusts the intensity values. The function *histogram_equalization.m* first converts the image into the *HSV* color space. The command *histeq*, provided by MATLAB, matches the vector V to a flat histogram with 64 bins by default.

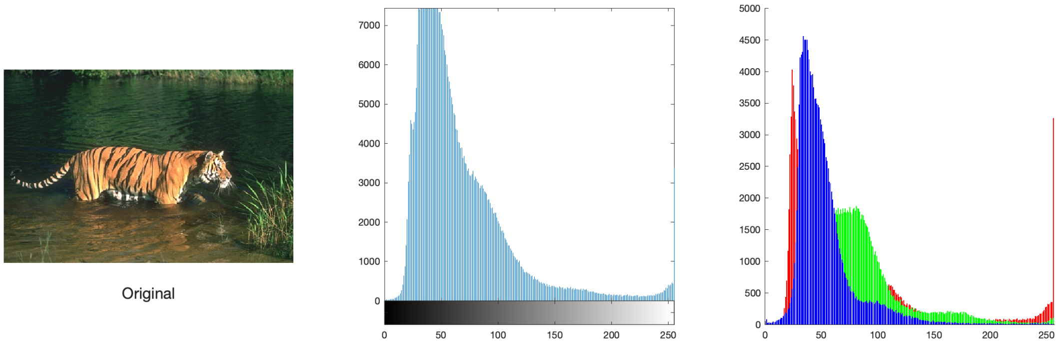
Figure 1.2 portrays the before and after of an image sample that has undergone histogram equalization. Note the increase in brightness and the color redistribution. In fact, the power consumption increased, a negative impact caused by the intensity equalization.

1.3. Contrast-limited Adaptive Histogram Equalization

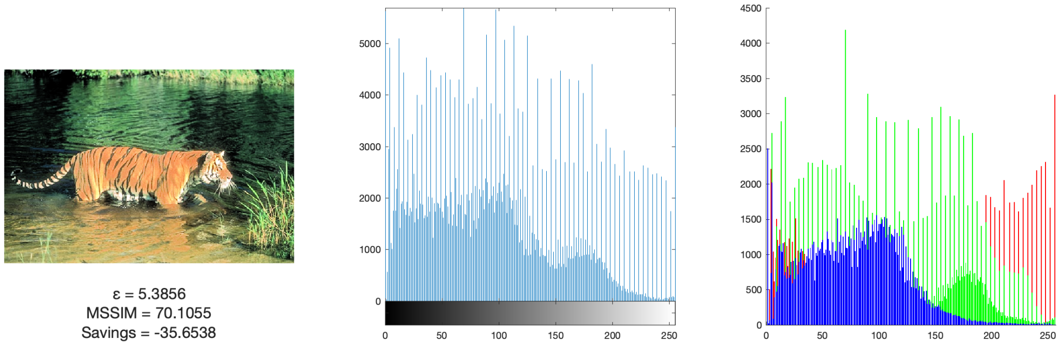
The Contrast-limited Adaptive Histogram Equalization (CLAHE) operates on small regions in the image, called tiles, rather than the entire image. Each tile's contrast is enhanced, so that the histogram of the region approximately matches an uniform distribution. The neighboring tiles are then combined using bi-linear interpolation to eliminate artificially induced boundaries.

The script *adaptive_histogram_equalization.m* converts the image into the LAB color space. The L channel must be scaled to the range expected by the *adapthisteq* function, [0 1]. Subsequently, CLAHE is performed over L, and the values are scaled back to the range used by the LAB color space. The new image is then converted back to RGB.

In Fig. 1.3 the same image sample as before has undergone this transformation strategy. In this case, a large difference in contrast can be perceived. Note how smoother the histograms are in comparison with those presented by Fig. 1.2 b).



(a) Before



(b) After

Figure 1.2: Histogram equalization.

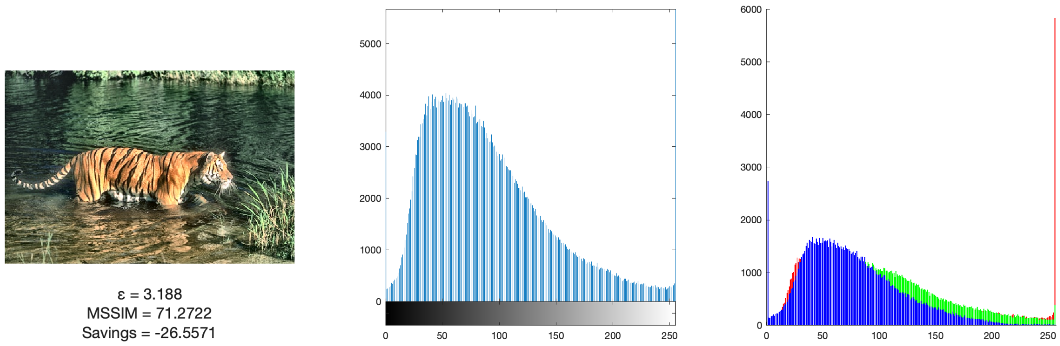


Figure 1.3: Contrast-limited adaptive histogram equalization.

1.4. Hybrid Transformation

The final technique is the combination of the previously described color reduction, in this case subtracting a fixed value from all color channels to avoid the side effect of having a green image, and the conventional histogram equalization for increasing brightness and contrast, otherwise the image would be too dark. The function *hybrid_technique.m* implements this transformation, the resultant image can be seen in Fig1.4. Note that with a mere 5% reduction 28% of energy is saved and the image difference is almost imperceptible.

Figure 1.4: Effects of color reduction on all channels and histogram equalization.

1.5. Results and Discussion

The combined strategy has been demonstrated to be quite effective for reducing power consumption. Table 1.1 presents the average measurements achieved with each iteration of the color reduction describe in Section 1.1 and the hybrid technique of Section 1.4.

The computed distortion and similarity rates for the pure color reduction transformation are substantially better, however, quality is subject to the observer and one could argue that the image quality of Fig. 1.1 is inferior w.r.t the images in Fig. 1.4. Despite the fact that the latter saved more energy, the green look of the first transformation could represent a problem for people affected by red-green color blindness.

	Savings [%]		Distortion [%]		MSSIM [%]	
Reduction [%]	Color	Hybrid	Color	Hybrid	Color	Hybrid
5	6.10	28.14	2.3307	4.7464	97.7150	81.2542
10	11.91	34.25	4.4357	5.6154	92.2191	76.0987
15	18.34	40.76	6.6032	6.5648	83.9838	69.9576
20	24.75	46.32	8.5896	7.3948	74.6823	64.2115
25	30.93	52.20	10.3547	8.2883	65.2609	57.6692

Table 1.1: Color reduction average measurements.

The histograms depicted in Fig. 1.5 compare both equalization strategies. Although the average distortion was 3.9110% for the conventional histogram equalization and 2.7566% for the adaptive one, none of these strategies were successful in saving energy by themselves, whose average was -4.3082% and -9.0236%, respectively. In conclusion, even the optimized equalization must be combined with a different technique in order to reduce power consumption, as the increase in brightness and contrast results into power overhead.

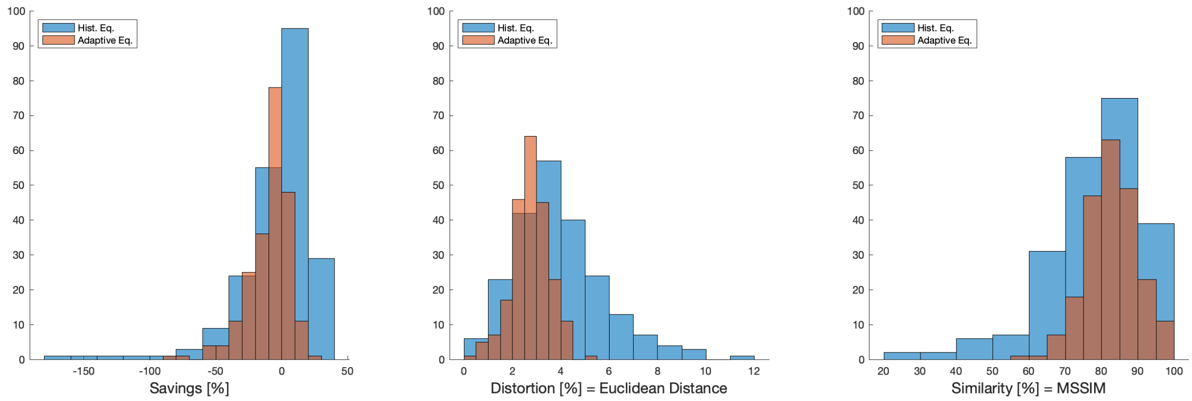


Figure 1.5: Results obtained with both equalization techniques.

2. Dynamic Voltage Scaling

The second part of this lab aims at experimenting with Dynamic Voltage Scaling (DVS) and evaluating software-based compensation techniques. The simulation flow is managed by the script *main2.m*. At each iteration the voltage supply is decreased by 5%, down to 75% of the default V_{DD}. Lower rates were not considered due to their impact on quality.

2.1. Brightness compensation

The function *brightness_compensation.m* takes as input the original voltage supply value as well the new voltage after scaling. For increasing brightness, a coefficient $b = \frac{V_{DD} * V_{DVS}}{V_{DD}}$ is added to each pixel intensity value in the HSV color space. Figure 2.1 depicts an image sample after undergoing both brightness compensation and voltage scaling.

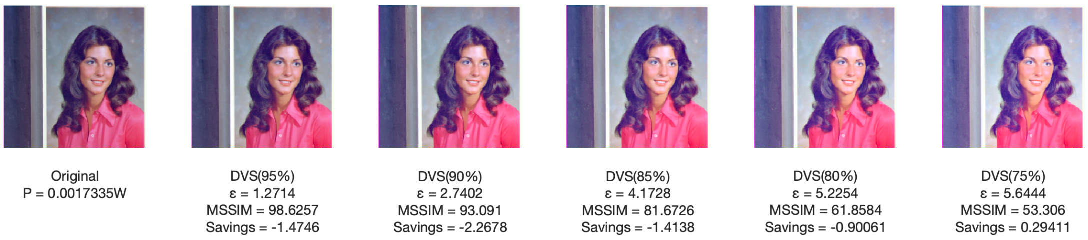


Figure 2.1: Brightness compensation effects.

2.2. Contrast enhancement

The function *contrast_enhancement.m* works similarly to the previous one, except that in this case the intensity value is multiplied by $b = \frac{V_{DVS}}{V_{DD}}$. Figure 2.2 displays the effects of this strategy, where the image is indeed rather sharper than brighter.

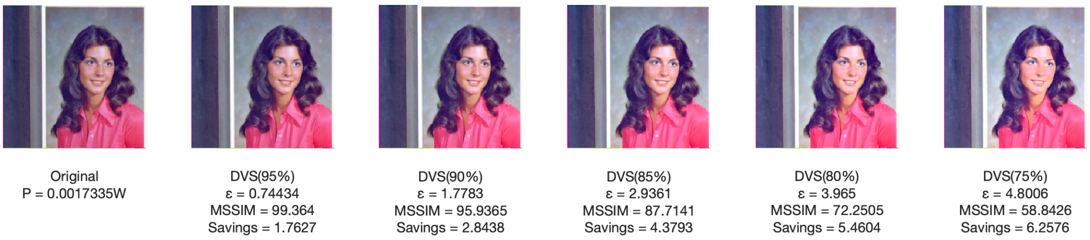


Figure 2.2: Contrast enhancement effects.

2.3. Concurrent brightness and contrast compensation

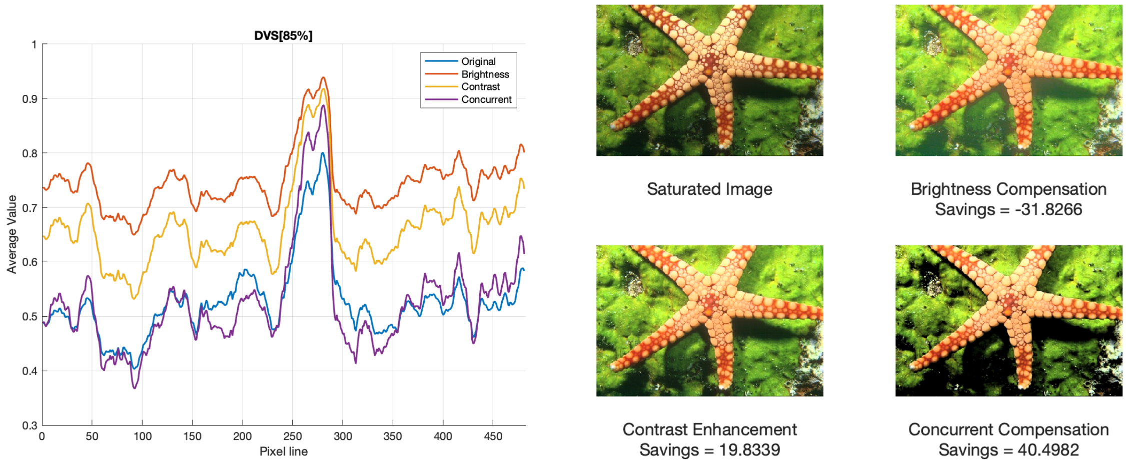
The function implemented by *concurrent_compensation.m* uses the brightness coefficient $gl = \frac{V_{DD} * V_{DVS}}{V_{DD}}$ as a lower boundary, while the contrast coefficient $gu = \frac{V_{DVS}}{V_{DD}}$ serves as the upper boundary. The intensity value is calculated through equation 2.1. Figure 2.3 illustrates the effects of this compensation technique.

$$t(x) = \begin{cases} 0, & 0 \leq x < gl \\ cx + d, & gl \leq x \leq gu, \text{ where } c = \frac{1}{gu - gl}, \text{ and } d = \frac{-gl}{gu - gl} \\ 1, & x > gu \end{cases} \tag{2.1}$$

Figure 2.3: Concurrent brightness compensation and contrast enhancement effects.

2.4. Results and Discussion

First, the effects of each compensation strategy on luminosity can be seen in Fig. 2.4. This plot correlates the average intensity value of each pixel in the vertical lines of the image sample depicted on right. Notice how the concurrent compensation curve almost overlaps the original one.



(a) Luminance **(b)** Image Sample

Figure 2.4: Concurrent brightness compensation and contrast enhancement effects.

Overall, the concurrent enhancement not only improved the image quality after voltage scaling as it saved more energy than the saturated image without any kind of compensation. Both contrast enhancement and concurrent compensation presented similar distortion rates.

	Saturated		Brightness		Contrast		Concurrent	
DVS[V_{DD}%]	Sav.[%]	Dist.[%]	Sav.[%]	Dist.[%]	Sav.[%]	Dist.[%]	Sav.[%]	Dist.[%]
95	5.1873	0.1679	-8.5468	1.5001	2.1247	0.7933	12.3448	0.7481
90	10.5752	0.4892	-15.0558	3.0366	4.6518	1.7160	22.3627	1.6529
85	16.1468	0.9957	-19.1584	4.4434	7.7741	2.7120	31.7599	2.6903
80	21.9046	1.7296	-20.3604	5.7018	11.7088	3.7340	40.6037	3.8649
75	28.1271	2.7715	-17.6505	6.6886	17.7549	4.7789	49.0929	5.2299

Table 2.1: Average savings achieved with each compensation technique.

Lastly, table 2.1 displays the average saving and distortion for each transformation. As expected from the previous experiments, the brightness compensation actually increased power consumption. Moreover, none of the strategies exhibited a distortion rate higher than 15% throughout the whole image-set.

3. Conclusion

The DVS strategy seems promising as a mean of reducing power consumption at a first glance. However, a 5% scaling using the concurrent brightness compensation and contrast enhancement from Section 2.3 yields an average energy saving of 12.35%, while the combined color reduction and histogram equalization technique from Section 1.4 was able to achieve 28.14% of savings in the same image-set with a 5% color reduction as well. The time to compute the software-based image transformation in both cases is unknown, as it depends on the system specifications. Therefore, considering that the first strategy certainly involves additional hardware resources for the voltage scaling, a trade-off between area and latency must be carefully evaluated in a real case.

Bibliography

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