Combined Local Dimming and Image Enhancement Technology for automotive Displays under Daylight Condition

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ABSTRACT

Automotive displays are operated under strongly varying ambient conditions. Local dimming may enhance visual quality in night drive, while image enhancement methods may mitigate daylight reflection. The scope of this paper is to investigate how the combination of local dimming and these image processing methods will impact the visual quality as well as the power consumption for an automotive display under daylight conditions.

1 Introduction/Motivation

A conventional active-matrix LCD consists of an optical stack containing an LED-Backlight unit (BLU), light guides and diffusers, polarizers, color filters and an LC-matrix. BLU is the decisive factor in terms of power consumption. Moreover, due to light leakage, where a real black level cannot be achieved, the image quality and contrast ratio is poor compared to OLED displays. For automotive applications this may already be a disadvantage for night conditions. For use under daylight conditions often the light intensity of the BLU must be increased to ensure readability of the display, which results in much higher power consumption.

For these problems local dimming and image processing methods may be applicable for mitigation of high power-loss and daylight reflection. In a local dimming algorithm, the BLU is dimmed according to the image content and BLU properties, resulting in power savings up to 50 %, [1].

Moreover, daylight deteriorates the image quality on the display, affecting legibility and readability, which are safety-relevant for automotive applications. A straight-forward method is to increase the luminance of the BLU. However, the high power consumption is a downside particularly for EV, in addition to higher cost for LEDs and thermal management. A too bright display may even glare the driver. Instead of increasing the brightness of the BLU, one could implement image processing methods to adapt the LCD RGB values instead. In this way daylight image enhancement may be implemented without significantly increasing power consumption, [2].

This paper aims to combine local dimming and daylight image enhancement and evaluate the benefits, like reduced power consumption and improved image quality on an automotive display.

2 Merits of Local Dimming and Daylight Image Enhancement

A physical local dimming model is described by the following equation.

$$Min\left\{\begin{array}{c}\sum_{i=1}^{k} LED(i): \\ \sum_{i=1}^{k} LSF(i)_{mxn} \cdot LED(i) = BL_{mxn} \geq IMAGE_{mxn}\end{array}\right\} \quad \mathbf{1}$$

The objective is to minimize overall power consumption which is proportional to the sum of LED currents. The constraint is that the backlight needed for an image given is generated or surpassed. The BLU property is described by the light spread function (LSF). The LED cross talk is considered by the Sigma function. Such a locally dimmed backlight assures that the luminance of every pixel may accurately be produced. This feature is essential, as images displayed may be safety relevant. Thus, such a physical model is proper for automotive applications.

So, the main merit of local dimming, particularly for operation under daylight conditions, is power saving, while the advantage of enhanced contrast ratio is mainly effective under night drive conditions. The power consumption for automotive HMIs may be reduced by typical 30 – 50%. Thus, local dimming is essential to limit power consumption and avoid overheating of the display.

One problem that remains, independently of local dimming, is the poor readability of display due to the display reflection of the high ambient light. A mitigation method is applying image processing like tone-mapping which is common for mobile devices. For automotive applications, there are safety requirements like ISO15008 which sets among other standards for luminance and local contrast. Thus, a specific daylight image enhancement method shall be applied which may comprise three steps: tone-mapping, edge enhancement and color mapping.

Due to the reflection of the display, low and medium gray values may be equalized or lose the differentiation to adjacent gray values. Thus, the EOTF (electro-optical transfer function) may be adapted depending on ambient light. The remaining contrast ratio between white and black shall reasonably be redistributed. This is also called tone-mapping [4].

For meeting local contrast specifications, edge enhancement may be applied. In figure 1, extremely strong edge enhancement even causes dark outlines. This artifact is acceptable, as it allows the fulfillment of ISO15008.

Fig. 1 Example of extremely strong edge enhancement

Reflection of the daylight makes color gamut smaller. The problem is similar like that of shrunk contrast ratio. Color processing shall redistribute the remaining gamut which is called color mapping. It may be based on the Yxy model, whereas x and y are a function of the ambient light. A good color mapping may make the image displayed be close to that without ambient light, [5], and appear more vivid than without color mapping.
Since daylight image enhancement strongly depends on the reflection characteristics of the display, a reflection model of LCDs was introduced and published, [2].

3 Reflection Model of LCDs

A possible image processing method to mitigate deterioration of the display performance under daylight conditions is based on a model describing LCD reflection characteristics, [2]. The luminance of the reflected light may be described by equation 2.

$$Y_{REFL} = Y_{CON} + Y_{LC} + Y_{DISP} \qquad 2$$

The reflection is described by three terms. The term Y_{CON} describes the constant specular reflections of light. Specifically, this means the amount of light that will be reflected without entering the LC layer, which can be described by equation 3.

$$Y_{CON} = f_{CON}(\theta, \Phi) \cdot L_{AMB}, \qquad 3$$

Whereas L_{AMB} describes the ambient light and f_{CON} a parameter.

In addition to the specular reflections of the light, the ambient light that enters the display will enter the LC panel via cell apertures, causing gray value (gv) dependent reflections. It can be differentiated between two cases. If the light is reflected inside the LC layer, the reflection caused by the liquid crystal molecules inside the layer may be approximated by the term Y_{LC}, in equation 4.

$$Y_{LC} = \sum_{i \in \{r,g,b\}} f_{i,1}(\theta, \Phi, gv_i) \cdot L_{AMB}, \qquad 4$$

whereas

$$f_{i,1}(\theta, \Phi, gv_i) = f_{i,1}(\theta, \Phi) \cdot gv_i^{\gamma},$$

The term gv^{γ} represents the transmission of the LC-cell. Moreover, a part of the ambient light will pass the LC layer, interact with the inner layers and sheets of the BLU and may be reflected towards the viewer. This reflection may be described by the term Y_{DISP}, in equation 5

$$Y_{DISP} = \sum_{i \in \{r,g,b\}} f_{i,2}(\theta, \Phi, gv_i) \cdot L_{AMB}, \qquad 5$$

whereas

$$f_{i,2}(\theta, \Phi, gv_i) = f_{i,2}(\theta, \Phi) \cdot gv_i^{2\gamma},$$

The square function considers the inwards and backwards path of the light through the LC cell.
Every parameter of this reflection model can be determined by curve fitting from measurements, as shown in figure 2, where the crosses indicate the measurement and the lines the corresponding curve fitting. Exemplary parameter values are listed in table 1.

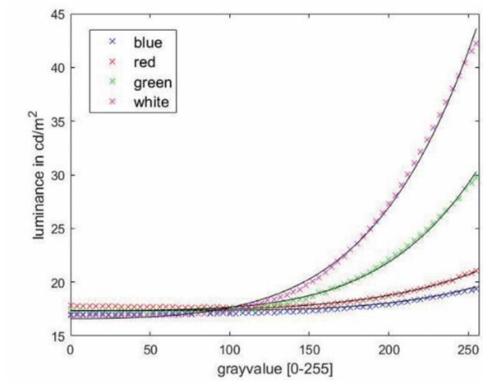

Fig. 2 Comparison between reflection model and measurement [2].

Tab. 1 parameters of the reflection model [2]

Parameter	Value
γ	2.354
f_{CON}	$2.7980 \cdot 10^{-4}$
$f_{R,1}$	$3.7935 \cdot 10^{-11}$
$f_{R,2}$	$8.5226 \cdot 10^{-16}$
$f_{G,1}$	$5.7161 \cdot 10^{-11}$
$f_{G,2}$	$8.5226 \cdot 10^{-16}$
$f_{B,1}$	$1.6823 \cdot 10^{-11}$
$f_{B,2}$	$2.3258 \cdot 10^{-17}$

4 Combined Local Dimming and Daylight Processing

For the implementation of combined local Dimming and daylight the setup in figure 3 was used. The setup consists of an LCD of 1920RGB720 with a 2400 LEDs backlight unit. To imitate daylight conditions a D65 illuminant with a maximum brightness of 62k lux was used (Figure 3). To simulate incident light this illuminant was placed at azimuth and elevation of 45° each.

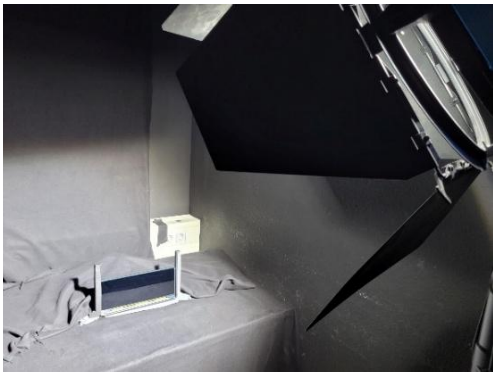

Fig. 3 Measurement setup consisting of a 2400 LEDs BLU and an LC panel.

The process flow of our combined Local Dimming and image enhancement method under daylight conditions is shown in Figure 4. The combined processing is implemented on an FPGA which delivers processed image data and control signals to this setup. The algorithm parameters for local dimming and daylight can be altered by a GUI.

First the daylight enhancement method for daylight condition will be applied. This enhancement method consists of three steps: tone mapping, edge enhancement and color mapping. The following local dimming procedure is based on the SSC algorithm [3]. By applying Gamma correction, the local dimming model will be transformed into a physical linear domain. To reduce computation effort the input image will be condensed, which will reduce image resolution and therefore simplify it. In the SSC Optimizer Core the LED duty cycles will be minimized by the use of an optimization procedure for the condensed, medium-resolution gray image, while considering BLU properties like LSF.

In the SSC optimization core, the pixels are scanned according to their position to the LEDs of the BLU. The constraint in equation 1, that the backlight luminance at each condensation cell is at least as high as the gray value of the condensation cell ensures a clipping-free solution. In the next step the LED values from the SSC Optimizer Core will be used for pixel compensation. In this step the linear image data is reconstructed to fit with the adapted backlight distribution. The goal is to achieve the same brightness pixelwise as without local dimming. Afterwards, the Degamma function transforms the linear transmission data into gamma-coded RGB values.

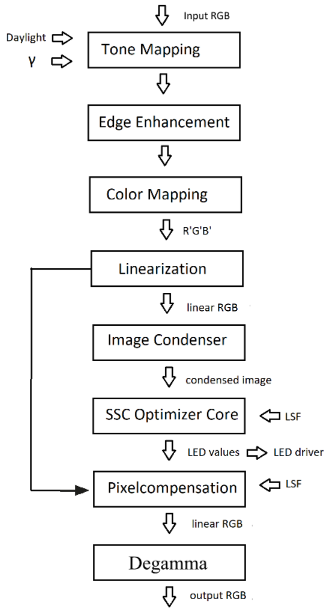

Fig. 4 Process flow of combined local dimming and image enhancement method.

5 Experimental Results

For one HMI image, the visual appearance under daylight is captured by a consumer camera and shown in figure 5.

Fig. 5 A locally dimmed automotive HMI with (top) and without image enhancement (bottom).

As one can see from the numbers in table 2, the power saving with the image enhancement for daylight condition are decreased compared to the case where just Local Dimming is applied (51% → 43%). The reason is that the image is brightened for enhancing readability and meeting ISO-standard.

Tab. 2 comparison of power saving rates

Image	local dimming	combined processing
	51 %	43 %
	53 %	43 %
	42 %	38 %

Figure 6 shows a cutout of a luminance measurement of the HMI from Figure 5 with and without image enhancement. In this case the luminance of sign 20 is doubled and despite daylight readable. Small detail like the circular line is clearly visible thanks to the image enhancement method.

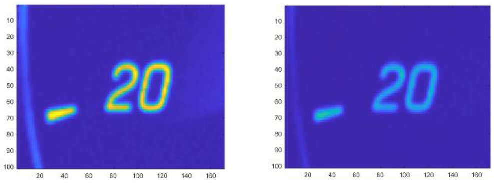

Fig. 6 Luminance Measurement with (left) and without image enhancement (right).

The upper part of figure 7 plots a normalized luminance distribution with (red) and without (blue) image enhancement at the vertical position pixel 618, marked by the red arrow in figure 5 . In the lower part of figure 7 the difference of both plots is displayed. Positive differences are mainly caused by tone-mapping and secondary by color mapping, while negative differences are caused by edge enhancement.

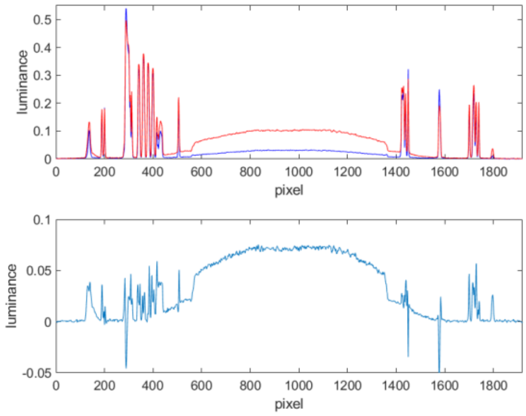

Fig. 7 comparison of luminance with and without image enhancement for a horizontal cut of the luminance measurement for image 5.

Local luminance are enhanced such that the perception of the image displayed is close to that without ambient light. Areas brightened have originally dark or medium gray values. Thus, the impact on power consumption is modest.

Power saving rates of the combined processing and just local dimming for three exemplary images are listed in table 2. The surplus of power consumption is in any case worth it. The logic complexity of the combined processing is roughly the sum of both procedures.

6 Conclusion and Outlook

Power saving is a decisive factor of automotive displays, particularly under daylight conditions. This paper shows the impact of combined local dimming and image enhancement methods for daylight condition. The merits of both technologies, power saving and better readability are combined. The procedure first executes the daylight image enhancement and subsequently the local dimming process. The method is implemented on FPGA and has been validated on a demo system under daylight lamp. The results show that the difference in power consumptions between with and without image enhancement are insignificant. More importantly, safety requirements and standards for automotive applications particularly for daytime operations can be met.

The work on this paper may be continued. One additional component that does not directly relate to local dimming or daylight condition but may still be interesting. It is the insertion of white balance in the shown process flowchart of the combined local dimming and image enhancement implementation. Through white balance, further spaces for both processing may get available yielding better results.

References

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