High Dynamic Range Video Streams Based on Inexpensive Image Sensors

Sheng-Yi Peng, Yu-Chi Wu, and Pao-Chi Chang
Department of Communication Engineering
National Central University
Jhongli City, Taiwan, ROC.
pcchang@ce.ncu.edu.tw

***Abstract* —This paper proposes a High Dynamic Range (HDR) system with low computation complexity based on inexpensive electronic devices. It utilizes advanced hardware structure with CMOS sensors that can generate multiple frames consisting of long and short exposures. In addition, the interval time between long and short frames can be set to a few msec or even less.**

Existing HDR recovering and compression techniques are used in the proposed system. Both the regular mode and the HDR mode share the same image processor and keep the same sensor characteristics. It exhibits minimum impact to the image processing unit while demonstrates excellent HDR performance.

Keywords—*high dynamic range, digital photography, image processor.*

I. INTRODUCTION

Over the years, there were many high dynamic range (HDR) researches going on because of the great demanding for high quality images from various image capture conditions. There were different viewpoints of the HDR technique. Some of them focused on how to create great quality or low artifacts, such as halos and noise, using advanced numerical calculation methods accompanied by high computation complexity. Some focused on the real-time processing based on the efficient and probably dedicated hardware system. Some utilized high quality Complementary Metal-Oxide-Semiconductor (CMOS) products that had larger well capacity and more accurate analog-to-digital converter. This enabled the sensor array to generate high contract images by itself without graphic processing.

All these numerical calculations or improvement methods need very complex computations and/or high costs. However, in applications such as mobile phones, HDR is only an option for high contrast or backlit scenes. It might not be necessarily worth spending extra cost for HDR. There exist many approaches to obtaining an HDR image from several different exposure images. Basically, it can be classified to two approaches.

The first approach is tone mapping technique. Although display devices that can support HDR video already exist, most display devices such as mobile phones or car kits can only support limited dynamic range video. Tone Mapping needs an intermediate step to create an HDR image from multi-frame images, then transform to low dynamic range image (LDR) for display.

The second approach is the exposure fusion technique [1]. It skips the intermediate step of creating a HDR image, directly uses the information of multiple images, such as contrast, saturation, and luminosity to obtain a fused image. However, the computational complexity is high and not easy for real-time applications. On the contrary, some of the tone mapping methods has the advantage of easily implementation.

The motivation for this work is to design an HDR system with very simple devices that can support HDR mode and video stream without extra image processors or other specifically designed external back-ends devices. An advanced hardware structure with CMOS imaging sensors was utilized for our development. It can supply two different exposure frames, long and short exposures, at the same frame time.

Many HDR research works focused on the static images processing. However, it is more challenging to work with video streams. For example, human visual is very sensitive to the brightness flickers, which could be caused by the normalization operations. In this work, we consider the entire work flow, including sensor output, processing of the image signal processor (ISP), recovering high contrast, and final tone mapping to display.

II. PROPOSED METHOD

The proposed HDR system is divided into several parts as follows for discussion.

A. Advanced HDR CMOS sensor unit

This CMOS sensor unit can generate long and short exposure frames in one frame time. Fig. 1 shows the exposure diagrams for traditional structure and the advanced structure that is used in this work. The advanced hardware structure of the sensors is able to efficiently use the interval time between long and short exposure frames. This advantage also drastically reduces the damage from the ghosting effect, which usually costs a large amount of resources in computation, for processing such as motion blur or fusion techniques [2]. The interval time could be made less than a few line-time of exposure depending on the short exposure time. Moreover, the processing of long or short exposures just needs to change the integration time, not sensor characteristics.

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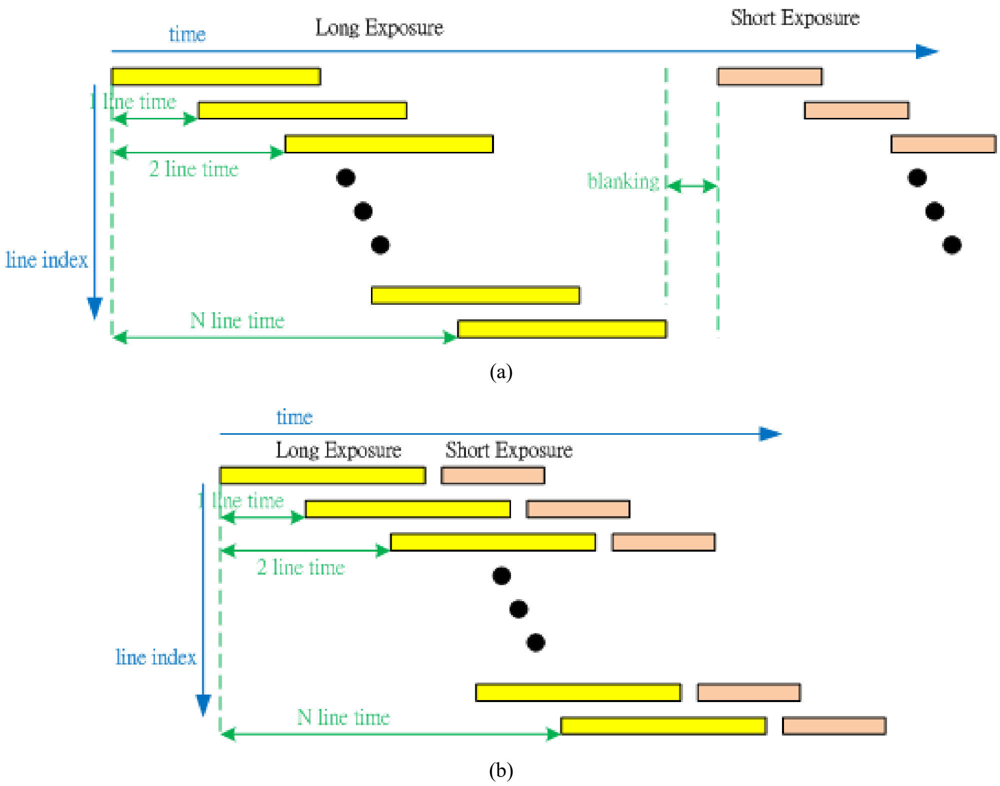


Figure 1. The exposure diagrams (a) Traditional hardware structure, (b) advanced hardware structure.

B. Recovering HDR image

Since we've got the multi-exposure images output from CMOS sensor, Debevec and Malik [1] proposed a method for recovering to HDR image. The relationship can be represented by (1)

$$f^{-1}(Z) = E\,\Delta t \qquad (1)$$

Where E is the irradiance value and $\triangle t$ is the integration time. The output Z (pixel value) is generated based on the photoelectric conversion process representing function f. This method shows how to solve function g, where $g = f^{-1}$. The function g represents the irradiance response characteristic of the sensor. To reduce the computational complexity, the function g is slightly modified to be linear, shown as in Fig. 2. Hence the function g can be expressed as the form of $Ax + b$, and it can easily be generated by a table with two factors. On the other hand, the ideal sensor response for irradiance should be linear. We think that the reason of the nonlinearity is caused by the non-ideal sampling images when solving g-function. We have found that nonlinear part is usually on the top or bottom of pixel value, which are the limitation of the analog to digital converter (ADC) range. For the purpose of close to ideal sensor response, using center parts can extrapolation the rest of it.

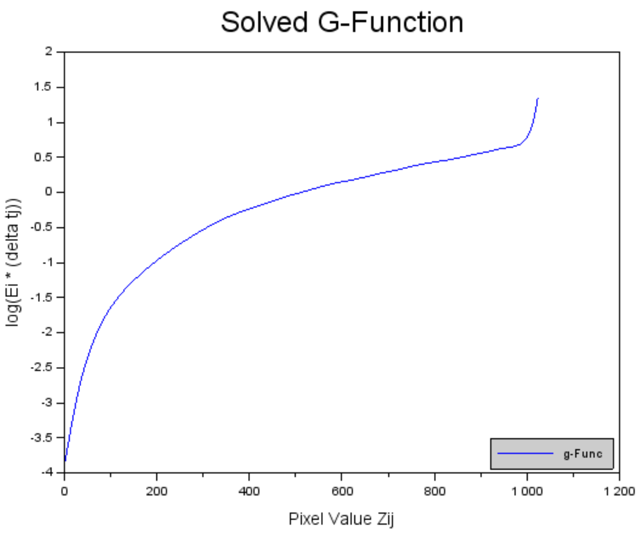
The color performance of the original and modified g functions is shown in Fig. 3. The degradation from modified g function is tolerable in most applications, some of the region close to brightest is even better. As we can see the paper on the desk is still white, but the lamp on the top is a little reddish while using nonlinear g-function.

We can create two g-function lookup tables for each exposure frame. The Debevec's method uses weighted sum to recover the high dynamic range radiance value. Finally the system just chooses the well-exposed value from the two possible candidates, as in (2).

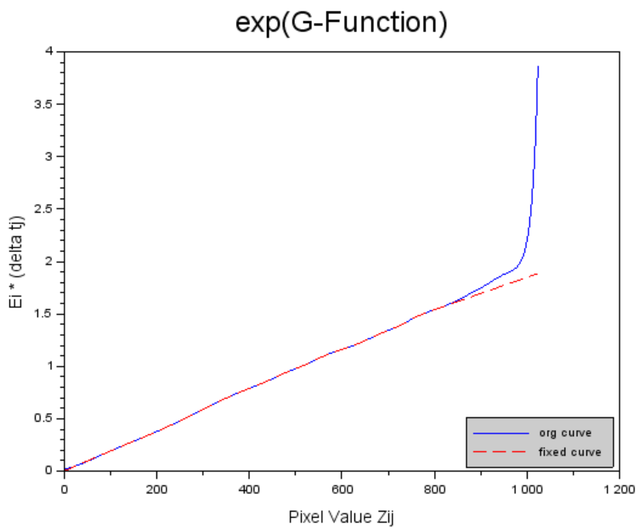
$$Ei = \begin{cases} \omega(Z_{sh}) \geq \omega(Z_{lg}) - n\,?\,g_{sh}(Z_{sh}) : g_{lg}(Z_{lg}), & \text{for } Z_{lg} > Z_{mid} \\ \omega(Z_{sh}) - n > \omega(Z_{lg})\,?\,g_{sh}(Z_{sh}) : g_{lg}(Z_{lg}), & \text{for } Z_{lg} \leq Z_{mid} \end{cases} \qquad (2)$$

Where $Z_{mid} = 1/2\ (Z_{min} + Z_{max})$, E_i is for the recovered radiance value, and ω is a hat function used in Debevec's method. Z_{lg} and Z_{sh} are the long and short frame values respectively. Note that n is the noise factor, which prevent $Z_{sh} > Z_{lg}$ when in dark or saturation regions. It can be measured by the pretesting stage.

The recovering process is done in the raw image domain. In regular image signal processing flow, the automatic white balance (AWB) calibration is arranged before color interpolation. In this system, the HDR recovering process is placed right after AWB calibration processing.



(a)



(b)

Figure 2. Modified g-function (a) g-function by Debevec's method, (b) g-function modified by slightly changing the exponential to linear (red dotted line).

C. *Tone Mapping (HDR->LDR)*

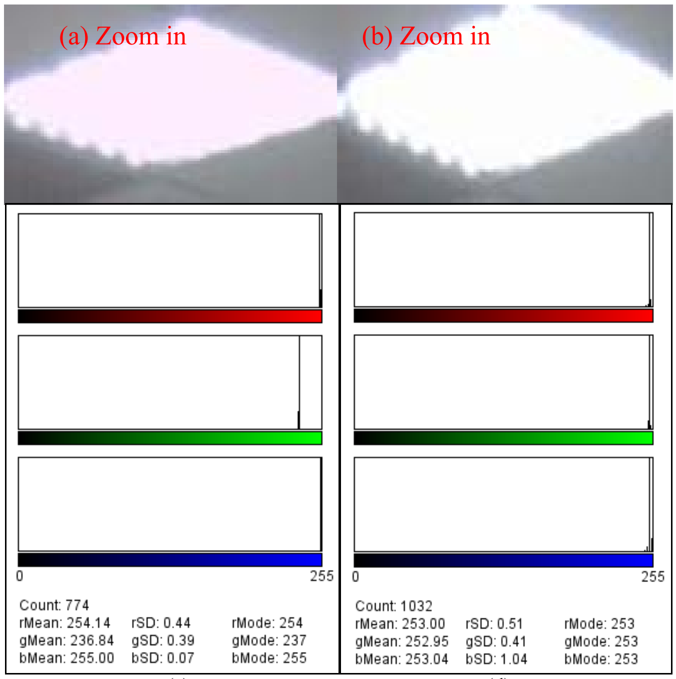
In the last stage of the system, it already gets HDR radiance value of each pixel. Since most of the display devices can only support LDR image/video, it is very challenging to convert HDR image down to low dynamic range (LDR) image to display, while maintaining good image quality. Using Reinhard global tone mapping method [2][4] , it can simply convert HDR to LDR image as in (3)

$$L_d = \frac{L}{1+L} \tag{3}$$

To extend contrast, we put a moving average filter to prevent brightness flicker while performing normalization.

(a)

(b)



(c) (d)

Figure 3. The color performance at the region of almost saturation. (a) Nonlinear g-function, (b) Linear g-function, (c) Zoom in for nonlinear's bright region and histogram, (d) Zoom in for linear's bright region and histogram.

III. Experimental Results

We set up an HDR environment to test our result. Testing CMOS sensor is based on 82M pixel clock rate (pixel / Hz) and 720p resolution, using D65 daylight light source. Capture two RAW images and combine into one.

(a)

(b)

(c)

Figure 4. Performance of the proposed HDR system (a) short exposure (simulating under exposure) frame raw image, (b) long exposure (simulating over exposure) frame raw image, (c) final HDR image.

IV. Conclusion

In this system, the whole HDR and LDR processes are completed before color interpolation. This also saves the memory and needs less parameter. The proposed HDR process provides excellent exposure, while maintaining good color performance. The HDR radiance value is recovered by table lookups and selection without any multiplication or division computations.

By using the global tone mapping method, the proposed system provides satisfactory computing speed, allowing devices to quickly display without additional hardware computing elements. This is particularly suitable for real-time consumer electronic products.

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