

# Ghost removing for HDR real-time video stream generation

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## ABSTRACT

High dynamic range (HDR) imaging generation from a set of low dynamic range images taken in different exposure times is a low cost and an easy technique. This technique provides a good result for static scenes. Temporal exposure bracketing cannot be applied directly for dynamic scenes, since camera or object motion in bracketed exposures creates ghosts in the resulting HDR image. In this paper we describe a real-time ghost removing hardware implementation on high dynamic range video flow added for our HDR FPGA based smart camera which is able to provide full resolution (1280 x 1024) HDR video stream at 60 fps. We present experimental results to show the efficiency of our implemented method in ghost removing.

**Keywords:** high dynamic range, exposure bracketing, ghost detection, real-time algorithm, smart camera, tone mapping

## 1. INTRODUCTION

Nowadays digital cameras suffer from low dynamic range since they use low dynamic range image sensors. These LDR sensors capture solely a limited luminance dynamic range (256 to 1024 levels) of the real scene. To overcome this limitation, the temporal exposure bracketing technique is widely used since it is a low-cost solution using a conventional image sensor. The high-dynamic image may be reconstructed using a HDR standard method in radiance domain, or by fusing LDR images directly in image domain producing an HDR-like image.

Temporal exposure bracketing solution suffers from ghost artifact when applied for dynamic scenes. The ghost artifact is the presence of an object in different location in the generated HDR image caused by the object or camera motion when capturing the set of LDR images (LDR images are spaced in time token for the same scene). To suppress this limitation a large number of ghost removing techniques are proposed in the state of the art. Some of the ghost removal techniques keep one occurrence of the moving object: K.Jacobs proposes an entropy based method [1] which uses the measure of local entropy differences to detect regions affected by moving pixels, these regions are excluded from the HDR generation process. S.Kang presents an optical flow based method [2]. T. Grosch proposed a prediction based method [3], he has compared the measured pixel value with a predicted value using the CRF, all diverging pixels from their predicted values are excluded from the HDR generation process. A probabilistic motion pixel detection method proposed by An et al [4]. The other group of the ghost removing techniques suppressed all detected moving objects in the scene. Pixel order based method [5] which detects the moving pixels if their values in low exposure is greater then their values in higher exposure. Gradient based method [6] detects the moving pixels if the gradient changes its direction and gives low weights for moving pixels and large weights for static pixels using the gradient information (direction, magnitude). Khan et al. proposed a density estimation based method [7] which is an iterative method that gives great weights for static pixels and small weights for moving pixels using density estimation.

To remove the ghost artifact we have implemented a modified version of the weighting function given in [8], based on the weights adaptation. The ghost removing is done before the HDR data generation step.

## 2. PLATFORM PRESENTATION

Our platform is a high dynamic range FPGA based smart camera. Our camera is an upgraded version of the HDR-ARtiSt [9]. This camera uses a Xilinx ML605 test platform board as a main board. The processing core is Xilinx Virtex-6 (xc6vlx240t). The ML605 board integrates a 512 MB SDRAM used to save 3 pictures with 3 different exposure times, then buffering these frames to the FPGA. We added a PCB module to the Xilinx mother board. This PCB module integrates an E2V (1280 x 1024) color image sensor used to capture frames with bracketed exposure technique. We added some communication interfaces like Ethernet 802.3 and a DVI output interface to save results on a host computer and show HDR tone mapped frames on LCD monitor respectively. All processing algorithms (HDR generation, ghost removing, tone mapping) and communication control interfaces (Ethernet and DVI) are implemented in hardware using VHDL description language.

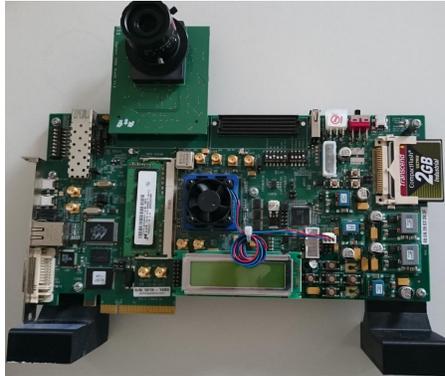


Figure 1. High dynamic range Xilinx FPGA based smart camera.

## 3. HIGH DYNAMIC RANGE GENERATION

To generate one HDR image, our camera fuses in radiance domain 3 low dynamic range images using the algorithm given by Debevec and Malik [10]. The algorithm uses 3 functions to construct the high dynamic range radiance map, recovered camera response function (CRF), weighting function (equ. 1) and a function to combine different exposures (equ. 2)

$$w(z) = \begin{cases} z - Z_{min} & \text{for } z \leq \frac{1}{2}(Z_{min} + Z_{max}) \\ Z_{max} - z & \text{for } z > \frac{1}{2}(Z_{min} + Z_{max}) \end{cases} \quad (1)$$

$$\ln E_{ij} = \frac{\sum_{k=1}^P w(Z_{ij}^k)(g(Z_{ij}^k) - \ln \Delta t_k)}{\sum_{k=1}^P w(Z_{ij}^k)} \quad (2)$$

where  $g()$  is the inverse log function of the CRF

$$g(Z_{ij}^k) = \ln E_{ij}^k + \ln \Delta t_k \quad (3)$$

## 4. GHOST REMOVING

To avoid ghost artifact, we have used a simple weighting function (equ. 5) inspired from the simple method based on weights adaptation given in [5] (equ. 4). The idea of both methods is to adjust pixel weights based on the deviation from the reference image [5]. The function gives a higher weights for pixels whose value are closed to the reference value and low weights for pixel whose value diverges considerably from a reference value.

We replaced the weighting function given by Debevec and Malik (equ. 1) by the weighting function (equ. 5) in the HDR combination equation (equ.2). Consequently to create high dynamic range images can be generated keeping the the same performances as the Debevec and Malik standard algorithm with a ghost removing in a radiance domain before HDR data generation.

$$w(Z_{ij}^k) = \frac{[a(Z_{ij}^{ref})]^2}{[a(Z_{ij}^{ref})]^2 + [(f^{-1}(Z_{ij}^k) - f^{-1}(Z_{ij}^{ref}))/f^{-1}(Z_{ij}^{ref})]^2} \quad (4)$$

$$w(Z_{ij}^k) = \frac{[a(Z_{ij}^{ref})]^2}{[a(Z_{ij}^{ref})]^2 + [(\frac{f^{-1}(Z_{ij}^k)}{\Delta t_k} - \frac{f^{-1}(Z_{ij}^{ref})}{\Delta t_{ref}})/\frac{f^{-1}(Z_{ij}^{ref})}{\Delta t_{ref}}]^2} \quad (5)$$

Where  $w(Z_{ij}^k)$  Weight of pixel at position (i, j) of the exposure k,  $f(Z)$  camera response function,  $\Delta t_k$  exposure time of image k and  $\Delta t_{ref}$  exposure time of the reference image. We have preserved the same function  $a()$  (equ. 6) function as given in [5].  $a()$  is a function of the pixel value in a normalized low dynamic range image reference to the [0,1] interval.

$$a(x) = \begin{cases} 0.058 + 0.68(x - 0.85) & \text{if } x \geq 0.85 \\ 0.04 + 0.12(1 - x) & \text{if } x < 0.85 \end{cases} \quad (6)$$

#### 4.1 Ghost removal hardware implementation

To implement the modified weights adaptation function, we have simplified it mathematically (equ.9) since it demands the use of an exponential operator to calculate the inverse camera response facton.

$$w(Z_{ij}^k) = \frac{[a(Z_{ij}^{ref})]^2}{[a(Z_{ij}^{ref})]^2 + [(\frac{f^{-1}(Z_{ij}^k)\Delta t_{ref}}{f^{-1}(Z_{ij}^{ref})\Delta t_k} - 1)]^2} \quad (7)$$

$$\frac{f^{-1}(Z_{ij}^k)}{\Delta t_k} = \exp [g(Z_{ij}^k) - \ln \Delta t_k] \quad (8)$$

$$w(Z_{ij}^k) = \frac{[a(Z_{ij}^{ref})]^2}{[a(Z_{ij}^{ref})]^2 + [\exp (g(Z_{ij}^k) - \ln \Delta t_k) - \exp (g(Z_{ij}^{ref}) - \ln \Delta t_{ref}) - 1]^2} \quad (9)$$

The simplification given by the equation (7) allows us to use 1 exponential operator in the weighs adaptation function. And the value passed to the exponential operator is limited (see equation 10), hence we can implement the operator with a few coefficients using Taylor series.

$$\max |(\ln E_i^k - \ln E_i^{ref} + \ln \Delta t_k - \ln \Delta t_{ref})| \leq 3 \quad (10)$$

The hardware implementation is fully pipelined and parallelized (2 hardware cores are used to calculate pixel weights of high and low exposures) to reach the system maximum frequency and frame rate. A simplified schematic of the hardware implementation of 1 wights adaptation core is given in the figure (2).

All arithmetic operators are floating point single precision (IEEE 754). The exponential operator has been implemented using floating point also, and it is fully pipelined.

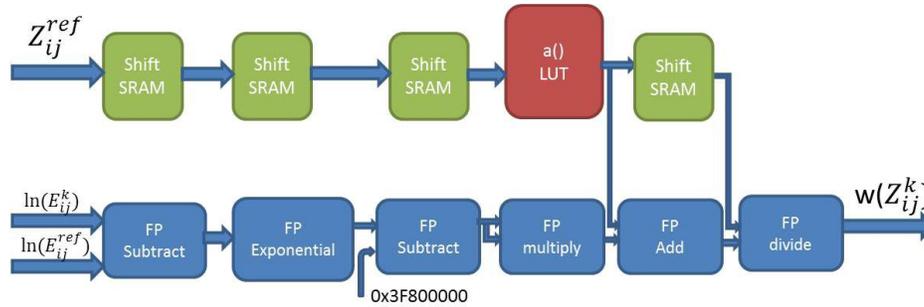


Figure 2. Schematic view of the wights adaptation core.



Figure 3. Set of LDR images, low exposure, medium and high exposure from left to right.

## 5. RESULTS AND DISCUSSION

To validate our method and before any hardware implementation, we have coded it in software. Since our ghost removal technique is done before high dynamic range generation by changing the Debevec weighting function by our weighting function, it was considered essential to test the influence of such change on the high dynamic range result and then test the ghost removing efficiency.

### 5.1 High dynamic range efficiency

To test the high dynamic range generation efficiency and accuracy, we generated a HDR images using the 3 methods: standard Debevec and Malik method, Debevec and Malik method using the weighting function given in [5] and Debevec and Malik method using our modified weighting function. Our method gives a good visual rendering (see figure:4 in left ) in bright region then the 2 other methods (figure:4) which seem to give the same result, and in dark region all 3 methods provide the same rendering quality.



Figure 4. HDR image results, Debevec and Malik standard method result, original weights adaptation function results and our modified weights adaptation function results from left to right.

To enhance our comparison we did an edge comparison between the result of our modified method and the result of the original one. Our method provides a good results in low light region where we can see more details highlighted using rectangles in figure:5 right. Using the original weighting function allows us to recover more edge details in lighting region which is highlighted using a rectangle in figure:5 left.

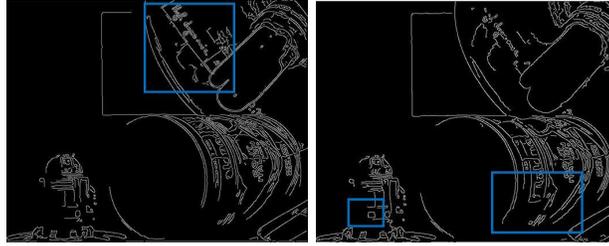


Figure 5. Edge of original weights adaptation function results left and the edge of our modified weights adaptation function results right.

## 5.2 Ghost removal efficiency

To test the ghost removing efficiency of the implemented method, we used a set of low dynamic range (LDR) images containing object motion (see figure:6). For ghost removal, both our modified weighting method and the original method give good results shown in figure:7. Our method removes ghost artifact as well as the original method comparing them to the high dynamic range generation using the conventional generation given by Debevec and Malik without any ghost removing process.



Figure 6. Set of LDR images with object motion, low exposure in left, medium and high exposure right.



Figure 7. HDR images using standard HDR generation, ghost removal using the original weighting function and our modified method from left to right.

## 5.3 The hardware implementation results

the figure: 8 shows the results given by our high dynamic range camera in real time at 50 frames/s. To do the test we have stuck down a box (we wrote "HDR TEST" in the bottom of the box) on a window (from which we can see car traffic) to create a high dynamic range scene, In this case we don't give the set of low dynamic range images, since our platform can not send to the host computer the set of LDR images and the HDR image result at the same time.

Our camera generates high dynamic range images without any ghost artifact which could be the result of cars motion in the street (see figure: 8). The HDR generation is done with a high accuracy where we can see more details on the outdoor (car traffic, clouds and sky) and indoor (the "HDR TEST" expression in the bottom of the stuck down box).



Figure 8. HDR image of a real high dynamic range scene taken by our HDR camera.

## 6. CONCLUSION

We have presented in this paper our modified method of HDR reconstruction, used to avoid ghost artifact in real time high dynamic range generation. The method of weight adaptation (the original weight adaptation function<sup>[5]</sup> and our modified weight adaptation function) gives good results in ghost removing. The hardware implementation works in real time but it is a logic consuming method since it uses a floating point operators. The implemented method added a small latency (0.95 us) to the high dynamic generation.

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