High Dynamic Range Real-time Vision System for Robotic Applications

P.J. Lapray, B. Heyrman, M. Rossé & D. Ginhac

LE2I UMR 5158, Univ Burgundy, Dijon, France
Email: Pierre-Jean.Lapray@u-bourgogne.fr

SCaBot'12, Thursday, October 11, 2012

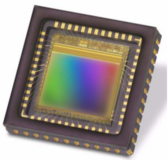
Summary

What is HDR imaging ?

- High Dynamic Range
- Dynamic Range is measured in stops. It is the ratio between the largest and smallest possible quantity of light. An increase of one stop is doubling the amount of light.

Limitations

A standard camera is able to capture only a fraction of the visual information. And a screen can display only a part of the digital information

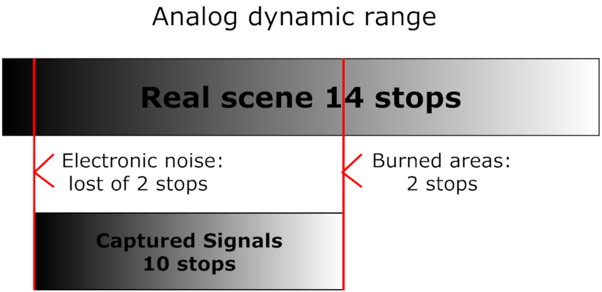


VS

What is HDR imaging ?

Limitation on capture

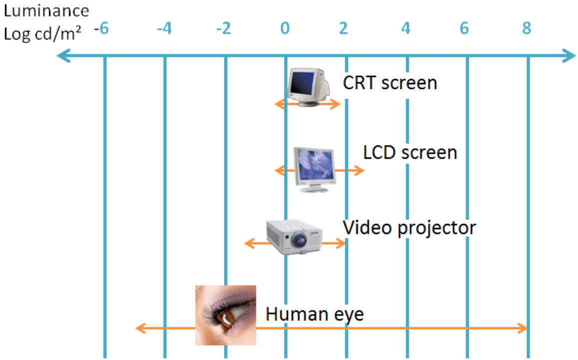
- For a digital camera, number of stops = bit precision of the ADC (ex : 10 stops for a 10-bit camera) camera
- Real scenes includes sunlit and shaded areas. When capturing a scene, the camera is unable to store the full dynamic range of the scene.



What is HDR imaging ?

Limitation on display

- The standard screens can not transmit directly a high dynamic range images
- The media used will determine a maximum tonal range to represent the digital file.



To overcome limitations

Limitation on capture

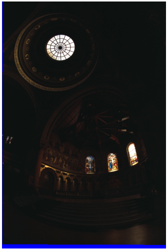
Solution : use multiple exposures and *HDR reconstruction solution*

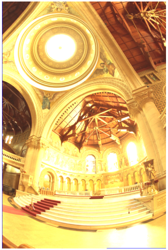
Limitation on display

Solution : perform *Tone Mapping* to reduce overall contrast and facilitate display of HDR images on devices

Exemple

- At left, an HDR image consisting of details in dark and illuminated areas
- Below, the acquisitions made by a camera.





Final goal

Final goal

By limiting the exposure time, the resulting image contains the details in high illumination areas. By increasing the exposure time, the resulting image contains the details in the dark areas.

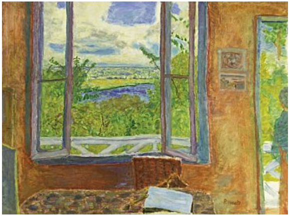


FIGURE: Painting by Pierre Bonnard.

FIGURE: HDR imaging exemple.

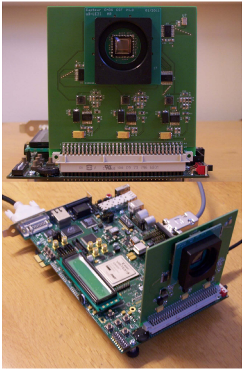
What's our goal ?

- Build a dedicated hardware camera on FPGA
- Perform multiple captures, HDR blending, tone mapping and displaying HDR contents in real-time
- 60 images/s image processing
- 1.3 Megapixels

Our hardware platforms

First prototyping platform : HDR video 1.0

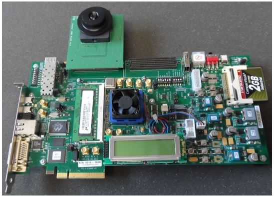
- A Virtex 5 FPGA development board (ml507)
- e2V sensor : 1.3 Megapixel, 60 images/s, high sensitivity, low power, global shutter mode
- Several communication interfaces : Ethernet, DDR2 SDRAM (256MB), serial interface, DVI...



Our hardware platforms

The second prototyping platform : HDR video 2.0

- A Virtex 6 FPGA development board (ml605)
- Same sensor as HDR video 1.0 : e2V sensor 1.3 Megapixel



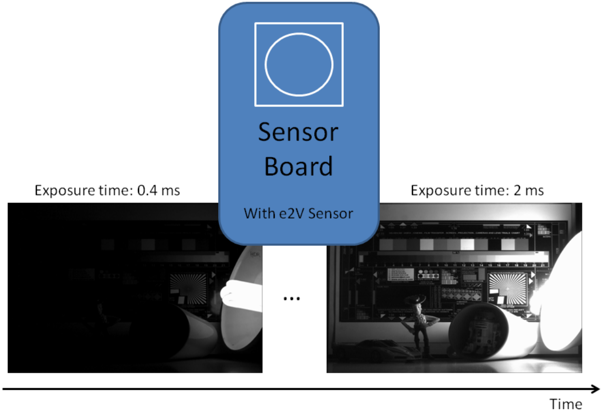
Benefits compared to 1.0 release

- Increasing the amount of FPGA space
- Increasing the bandwidth and the speed of the memory (DDR3)
- New low noise camera connectors
- Pin-compatibility with newer versions of evaluation boards (Virtex 7, Zinq etc.)

Summary

HDR capture

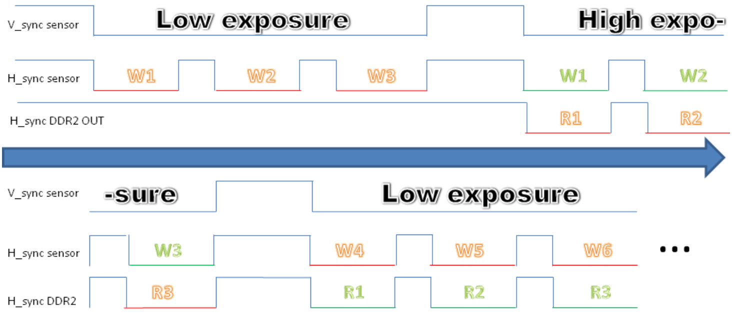
- The sensor is able to send successively 2 images with 2 different integration times at 60 frames/s
- The integration time varies rapidly during the capture



Memory Management

Frame buffering for HDR creating

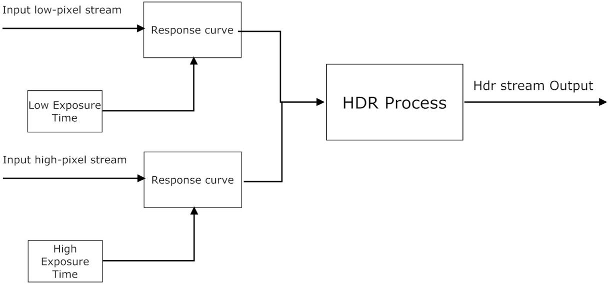
- While we receive one frame from the sensor, we read the last frame from the SDRAM memory and we write the current frame into DDR2 memory
- Finally, we have a 2 streams of Low Dynamic Range images in parallel



HDR Blending

Steps of Debevec et al. algorithm

- Having two images : one underexposed and one overexposed
- Knowing the two exposure times
- Knowing the response curve of the sensor
- Performing HDR Debevec algorithm for each pixel
- We've got an HDR stream, IEEE754 floating point values



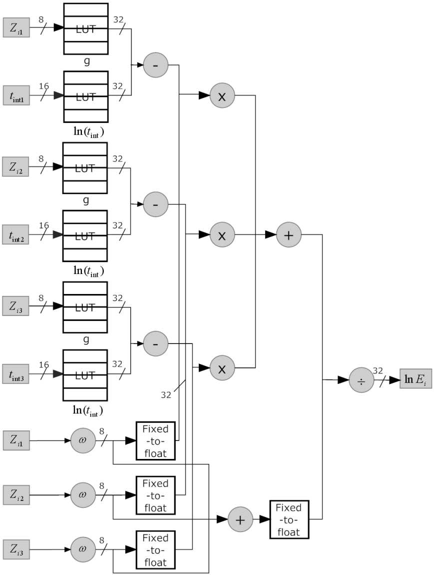
HDR Blending

Debevec et al. algorithm

$$\ln E_i = \frac{\sum_{j=1}^{P} \omega(Z_{ij})(g(Z_{ij}) - \ln \Delta t_{ij})}{\sum_{j=1}^{P} \omega(Z_{ij})} \quad (1)$$

Where $\omega(z)$ is the weighting function. It is a simple hat equation. E_i is the irradiance, Z_{ij} is the pixel value of pixel location number i in image j and Δt_{ij} is the exposure duration. The function g is defined as $g = \ln f^{-}1$. The response curve g is determined by resolving a complex quadratic function in C++.

HDR Blending



HDR Blending

Debevec et al. algorithm

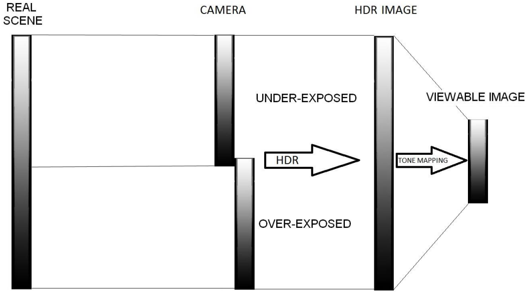
Device :	xc5vfx70t-1ff1136
Number of Slice LUTs :	5647/44800 (12%)
Number of Slice Registers :	5975/44800 (13%)
Number of Block RAM/FIFO :	6/148 (4%)
Number of DSP48Es :	4/128 (3%)
Maximum frequency :	184.536 MHz

TABLE: Summary of hardware synthesis report on Virtex 5

Tone mapping

Make the picture viewable : the Tone Mapping solution

- Skip IEEE754 32-bit format to 8-bit
- Allow on-screen standard display
- It is necessary to convert the HDR values to 8-bit integer values in such a way that all the details are still faithfully reproduced : we use the Duan et al. global algorithm.

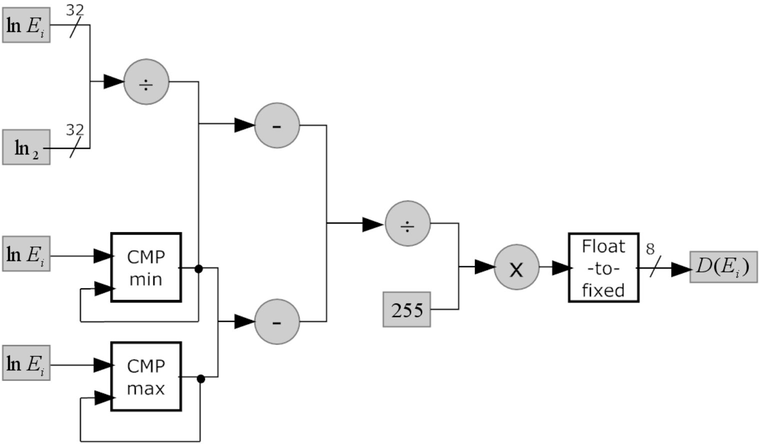


Tone mapping

Duan et al. algorithm

$$D(I) = C * (D_{max} - D_{min}) + D_{min}$$
$$with\ C = \frac{\log(I + \tau) - \log(I_{min} + \tau)}{\log(I_{max} + \tau) - \log(I_{min} + \tau)} \quad (2)$$

Duan et al. algorithm



Tone mapping

Duan et al. algorithm

Device :	xc5vfx70t-1ff1136
Number of Slice LUTs :	4784/44800 (11%)
Number of Slice Registers :	5025/44800 (10%)
Number of DSP48Es :	2/128 (1%)
Maximum frequency :	161.125 MHz

TABLE: Summary of hardware synthesis report on Virtex 5

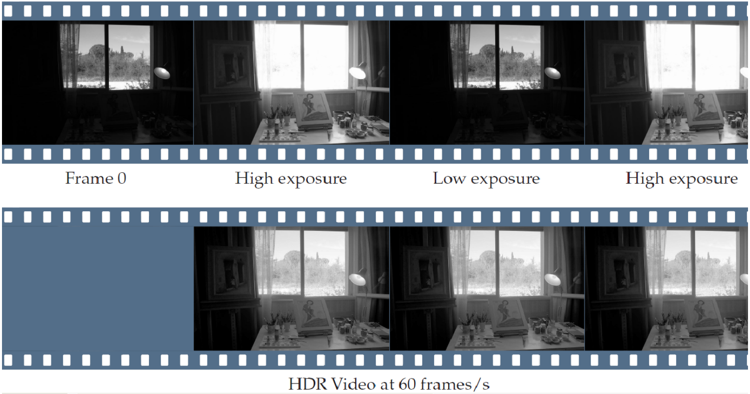
Global implementation

Global implementation

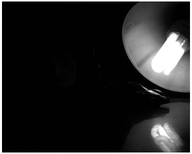
Device :	xc5vfx70t-1ff1136
Number of Slice LUTs :	13011/44800 (29%)
Number of Slice Registers :	8010/44800 (17%)
Number of Block RAM/FIFO :	18/148 (12%)
Number of DSP48Es :	6/128 (4%)
Maximum frequency :	128.236 MHz

TABLE: Summary of hardware synthesis report on Virtex 5

Results


Frame 0
High exposure
Low exposure
High exposure
HDR Video at 60 frames/s

HDR with two images

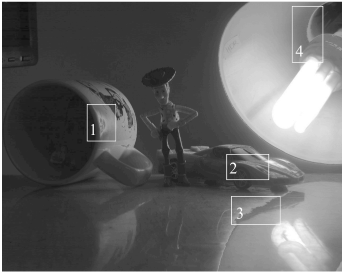


+

HDR with two images

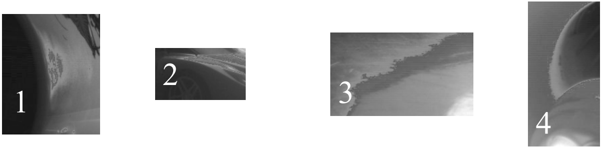
2 images.

Limitations



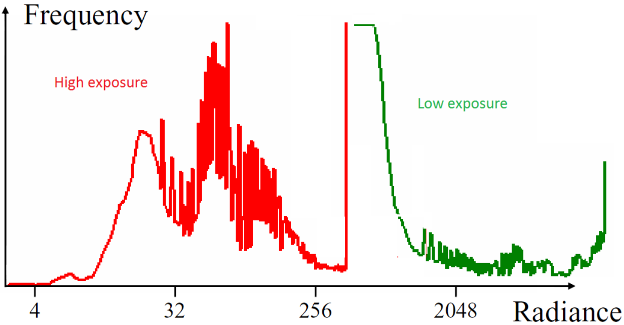
Result of hardware implementation of HDR with 2 EV

Result of hardware implementation of HDR with 3 EV



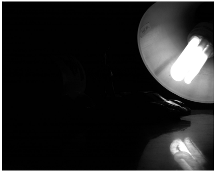
There are some artifacts with 2 images for this particulary captured scene. 3 images can overcome these limitations.

HDR with two images



3 images can overcome these limitations.

HDR with three images

 +  + 

High Dynamic Range Real-time Vision System for Robotic Applications

P.J. Lapray, B. Heyrman, M. Rossé & D. Ginhac

HDR with tree images

3 images.

Applications

Applications

- Mobile outdoor/indoor caméras
- Catch video in difficult conditions
- Defect control
- ...

Summary

Future

- We work on HDR creating from 4 or more images for comparison
- Develop a multiple exposure control in VHDL and select automaticaly the numbrer of images (1, 2 or 3) needed
- An UDP Ethernet communication to fetch video samples
- Implementation of more complex tone mapping algorithm.
- Implement a new technique in hardware called Exposure Fusion

Thank you

Thank you.

Vidéo sample

Additional informations

Curve g() :

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j \quad (3)$$

Z is a nonlinear function of the original exposureX at the pixel.

$$\mathcal{O} = \sum_{i=1}^{N} \sum_{j=1}^{P} [g(Z_{ij}) - \ln E_i - \ln \Delta t_j]^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} g''(z)^2 \quad (4)$$

Note that the curve can be used to determine radiance values in any image(s) acquired by the imaging process associated with g, not just the images used to recover the response function.

Additional informations

Weighting function :

$$\omega(z) = \begin{cases} z - Z_{min} \text{ for } z \leq \frac{1}{2}(Z_{min} + Z_{max}) \\ Z_{max} - z \text{ for } z > \frac{1}{2}(Z_{min} + Z_{max}) \end{cases} \quad (5)$$