Smart Camera Design for Real-time High Dynamic Range imaging

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Outline

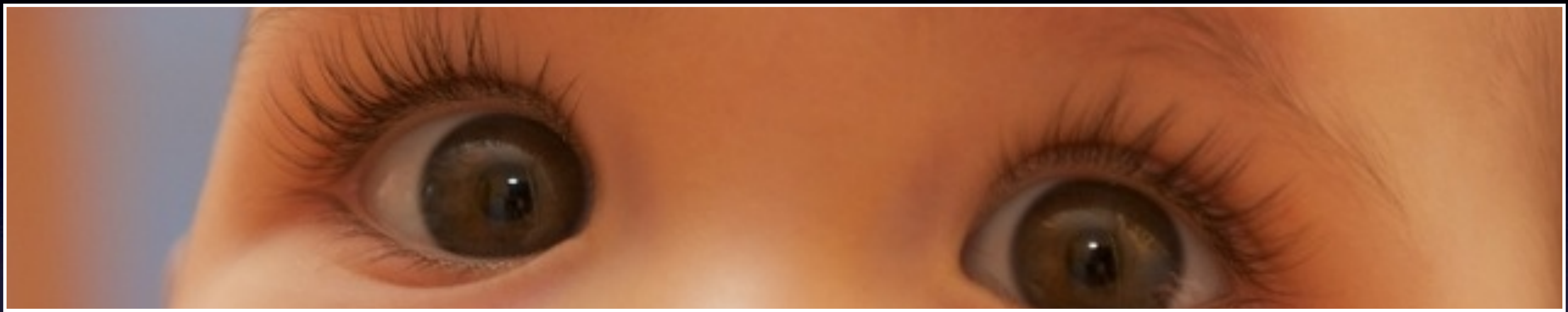
- What is HDR imaging ?
- Presentation of a standard HDR algorithm pipeline
- Our Hardware solution to implement realtime HDR imaging

What is HDR imaging ?

HDR imaging ?

- Dynamic range is the ratio between the maximum (white) and the minimum (black) measurable light intensities
- Dynamic Range is measured in Exposure Value (EV) differences or stops between the brightest and the darkest parts of the image
- An increase of one stop is doubling the amount of light of the image

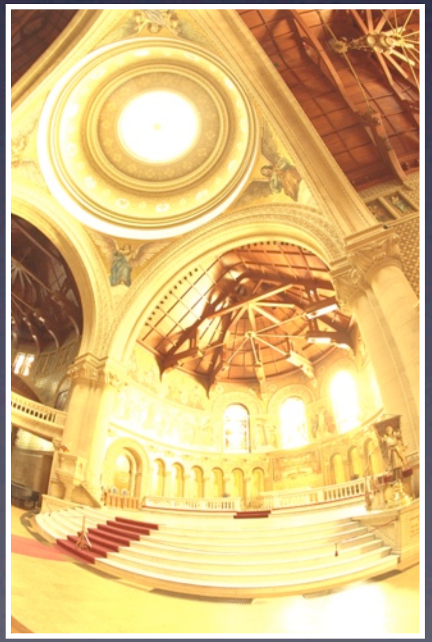
HDR imaging ?

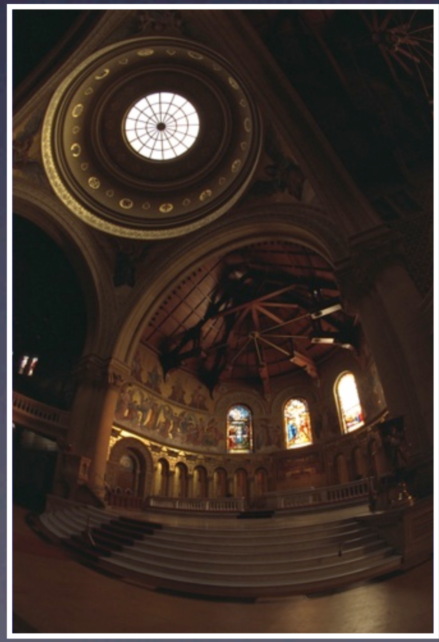


- Human eyes perceive a greater Dynamic Range than a digital camera
- For a digital camera, # of stops = bit precision of the ADC (ex : 10 stops for a 10-bit camera)
- For humans, up to 24 stops when our pupil continuously opens and closes for varying light and up to 14 stops with fixed pupil

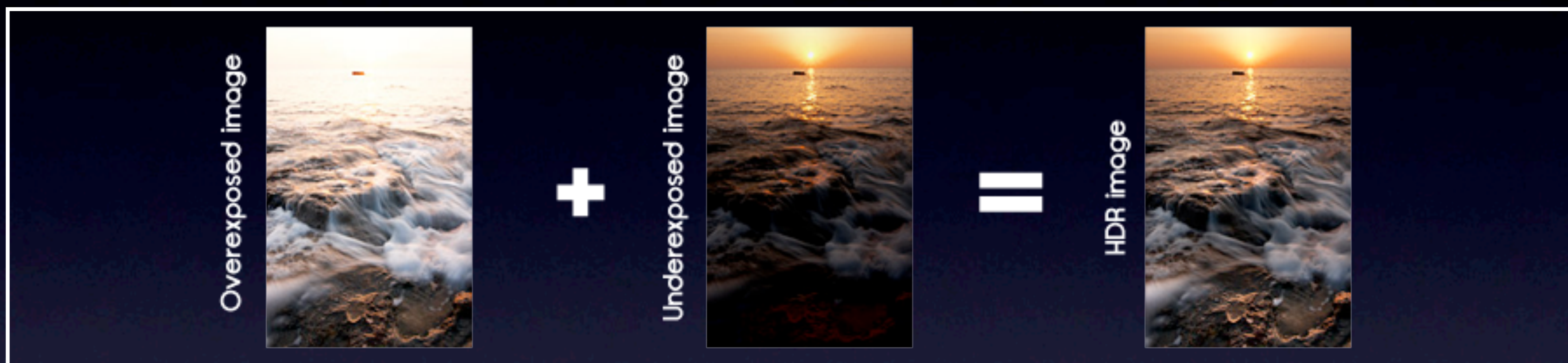
HDR imaging ?

- On the left, a HDR scene that can be perceived by an human eye with both details in dark and bright areas
- Below, acquisitions made by a digital camera with various integration times





HDR imaging ?

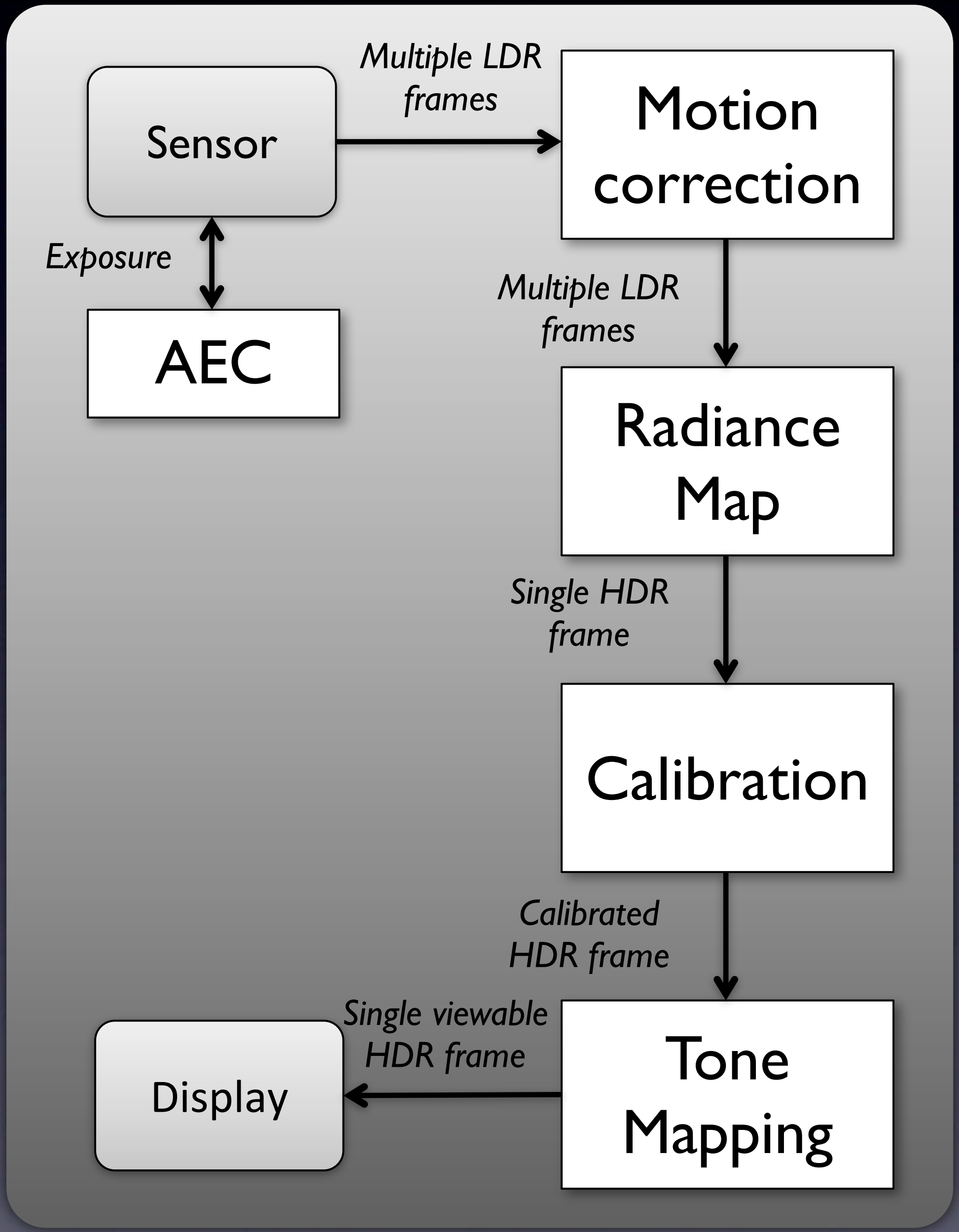


- High Dynamic Range Imaging is a set of techniques that allow a greater dynamic range than current standard digital imaging techniques or photographic methods.
- One solution is to combine multiple exposures Low Dynamic Range images into a greater looking HDR image that covers the full dynamic range of the scene

Standard HDR algorithm pipeline

HDR Algorithm Pipeline

- Estimation of the optimal exposures for multiple capture,
- Motion correction of the successive images,
- Computation of the radiance map,
- Calibration of the HDR image
- Local/global tone mapping for viewing on a LCD display



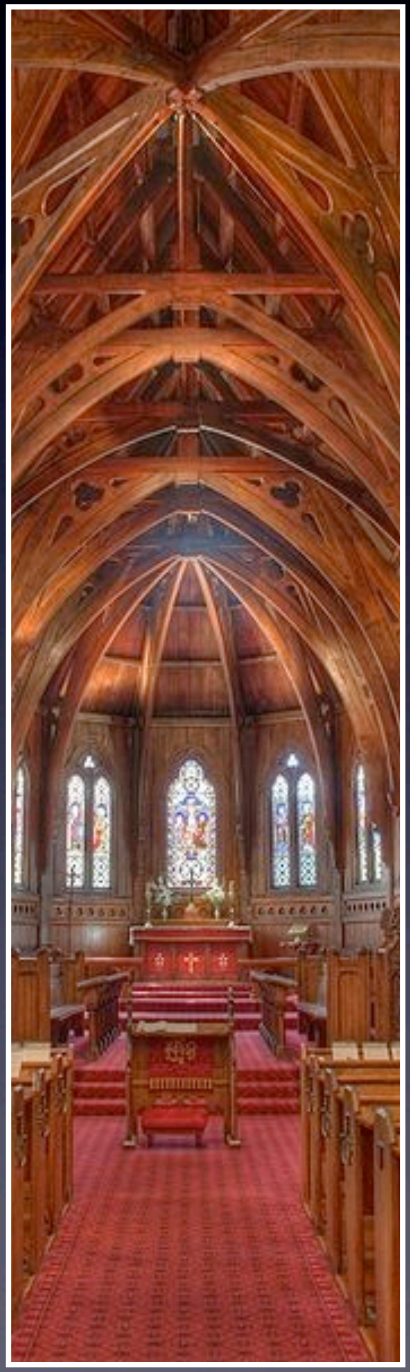
Auto exposure control

- Similar as autobracketing implemented in digital cameras.
- Performs captures of the same image with different exposure settings, both over exposed (brighter image) and under exposed (darker image) compared to a given exposure (medium image).
- AEC is a crucial step that needs to precisely and continuously evaluate exposure settings in order to capture a maximum of information in the scene.
- The candidate exposures must be automatically computed from previous captures on the basis of pixels statistics, such as histograms, ratio of dark or bright pixels.

Motion correction

- Each of the images must represent the same scene.
- For dynamic scenes with moving objects, multiple acquisition leads to motion artifacts and ghosting
- Global and local displacements in LDR frames must be corrected by complex algorithms based on optical flow, motion estimation, ...

HDR creating



- Pixel values are the result of a non linear function of the exposure linked to the characteristic curve of the sensor
- HDR creating requires 2 main steps:
  - Recovering the g function corresponding to the sensor response by minimizing the following equation:

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

  - Reconstructing the radiance map Ei for each pixel by combining the multiple exposure values:

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

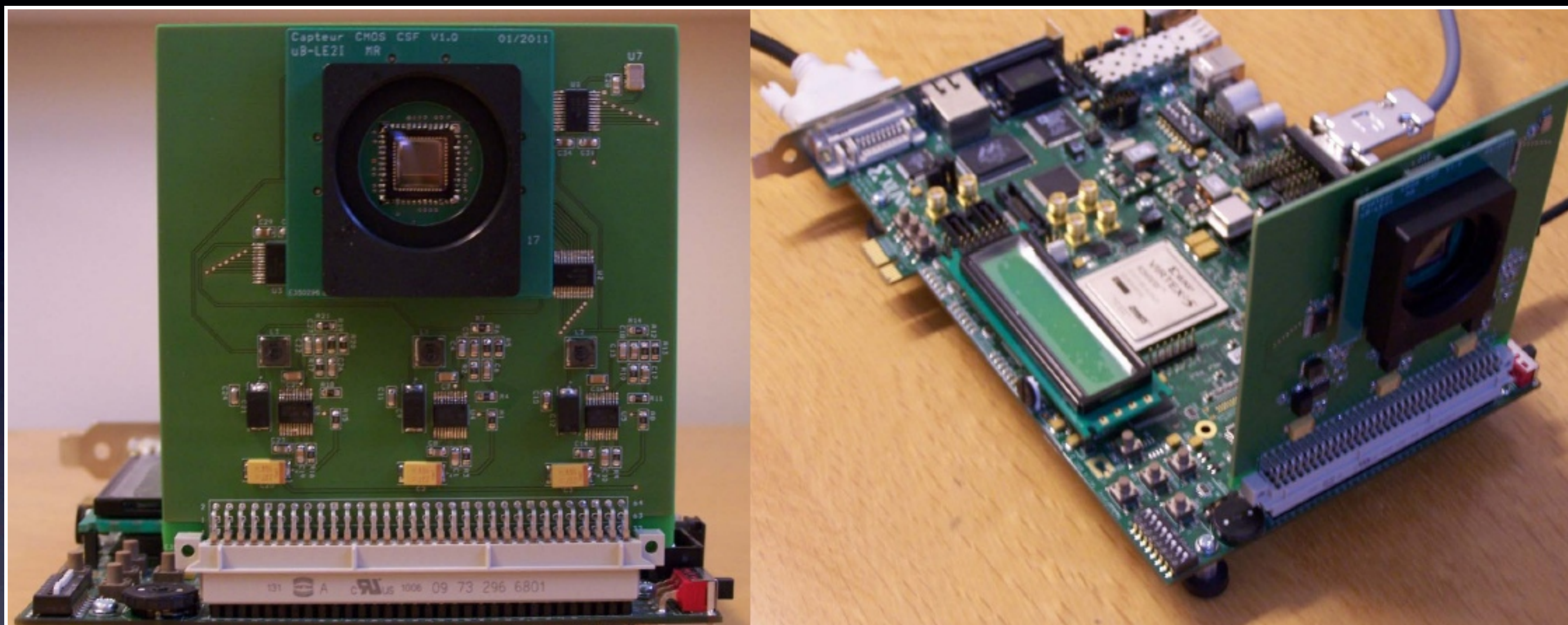
Calibration & Tone mapping

- A supplementary step dedicated to calibration is needed before performing the tone mapping operation.
- Tone mapping operators must have precise information about the light conditions to differentiate for example between day scene or night scene
- Calibrated pixels are estimated by using the distance of the log average luminance relative to the minimum and the maximum luminance of the scene.

Calibration & Tone mapping

- Last step of the HDR pipeline
- Performs conversion from HDR images to 8-bit values that can be displayed on a LCD monitor
- Two main categories of tone mapping operators:
  - Global operators which apply a single fixed mapping operation to each HDR pixel
  - Local operators which adapt the mapping function depending on the neighborhood of the pixel

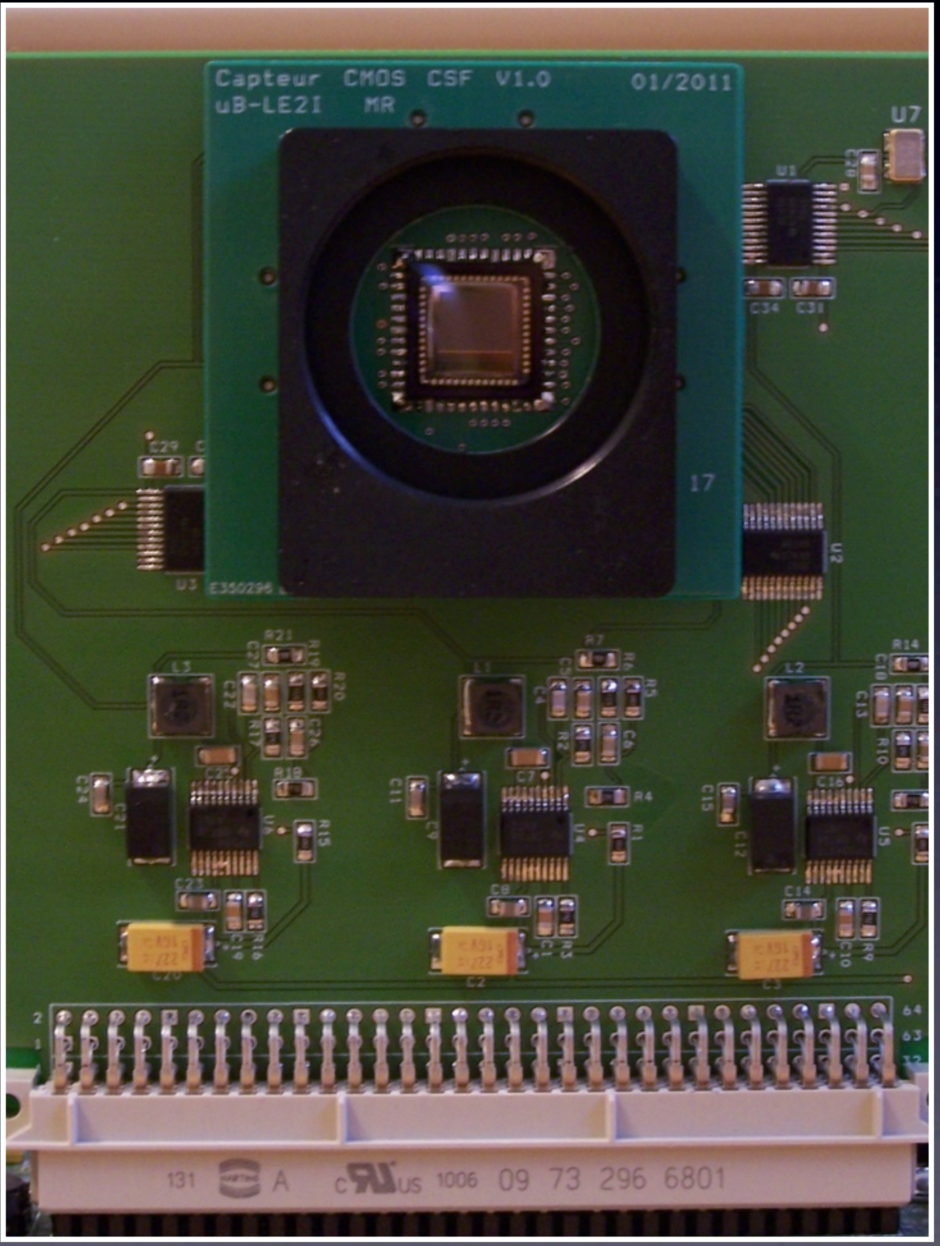
Our realtime hardware platform



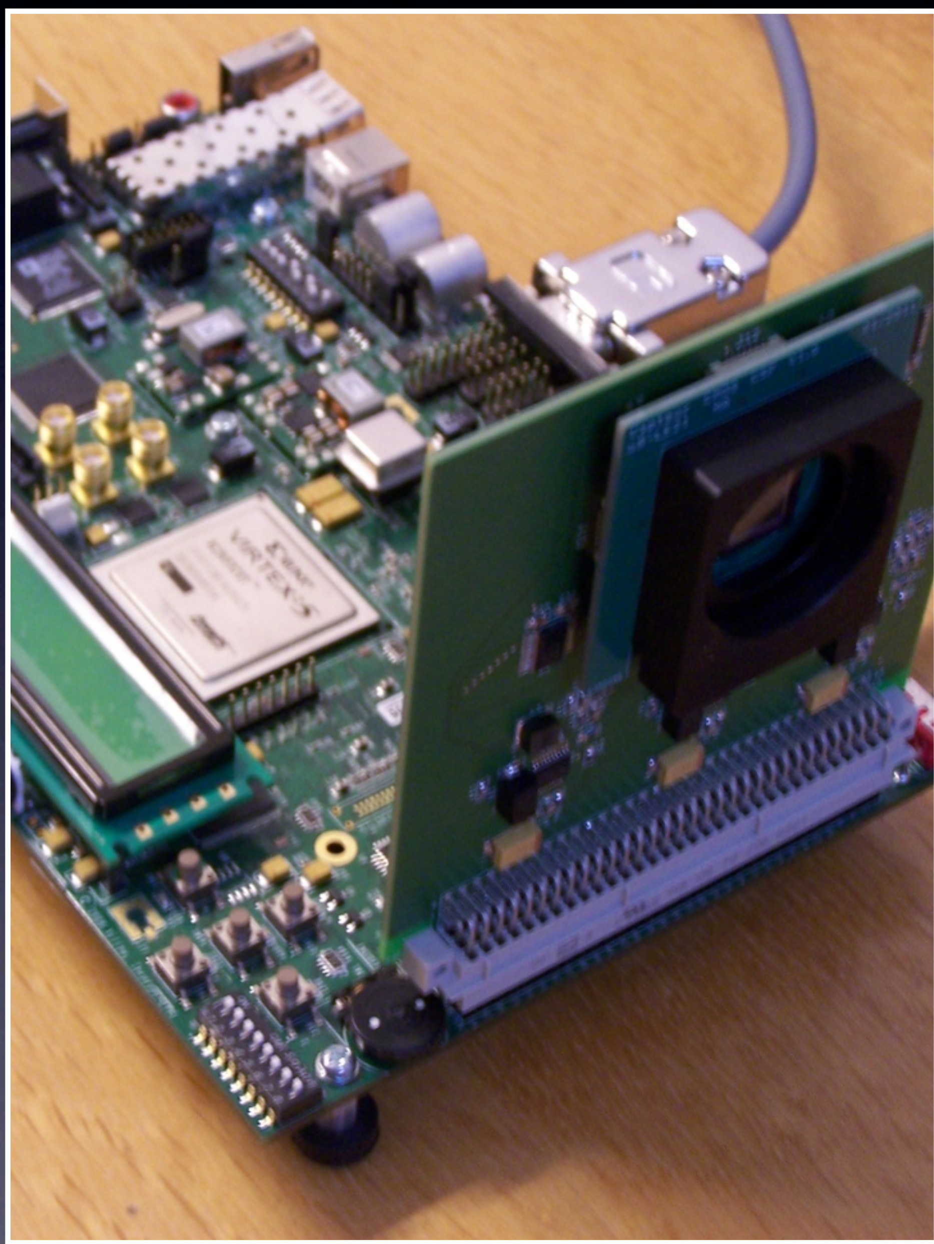
Specific HW platform

Image sensor

- Based on a EV76C560 sensor provided by e2v
- Resolution: 1280 x 1024 pixels
- 10-bit digital readout at 60 fps
- Embedded processing : histograms, number of saturated pixels
- Able to make an acquisition simultaneously with the readout of the previous frame



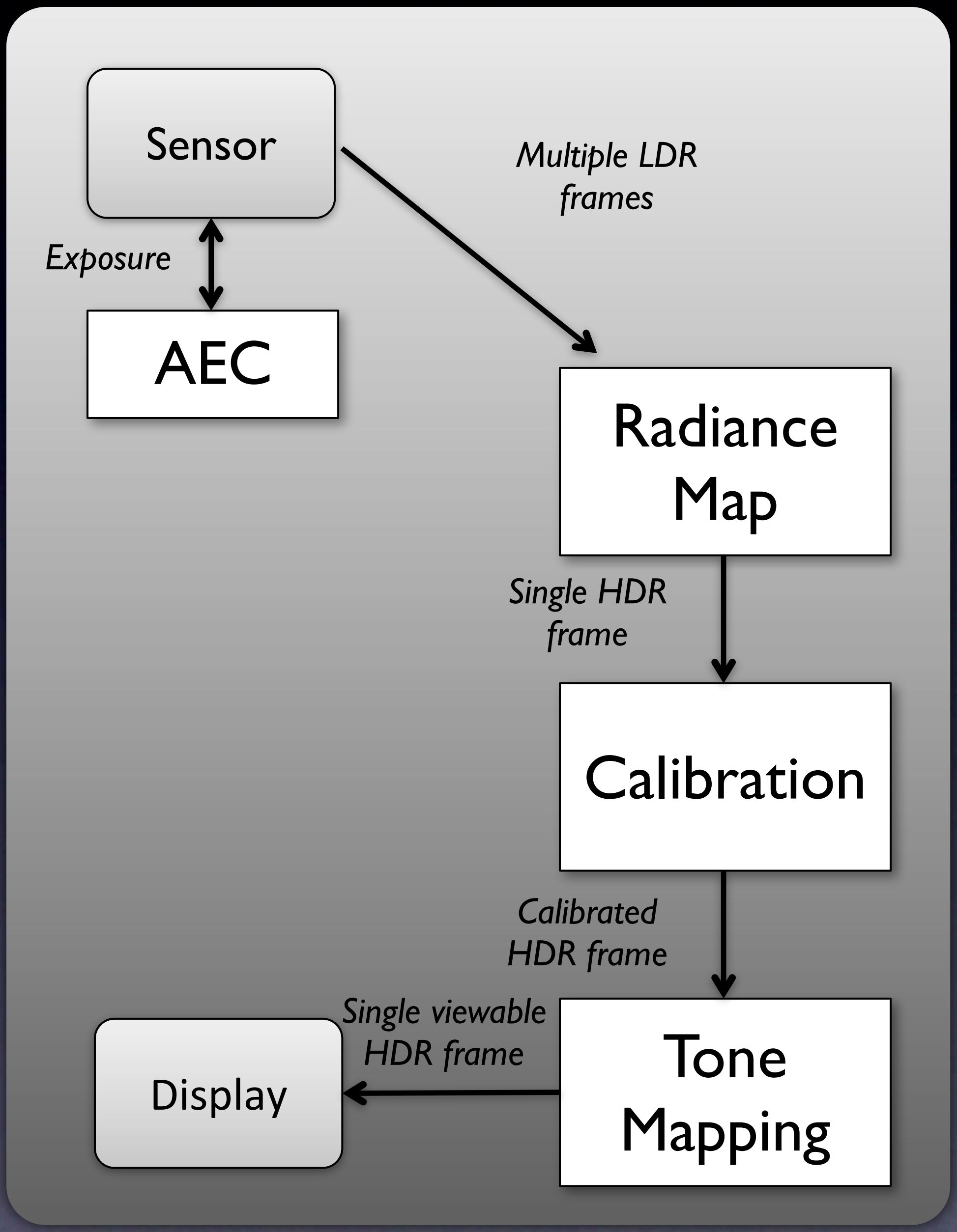
HW platform

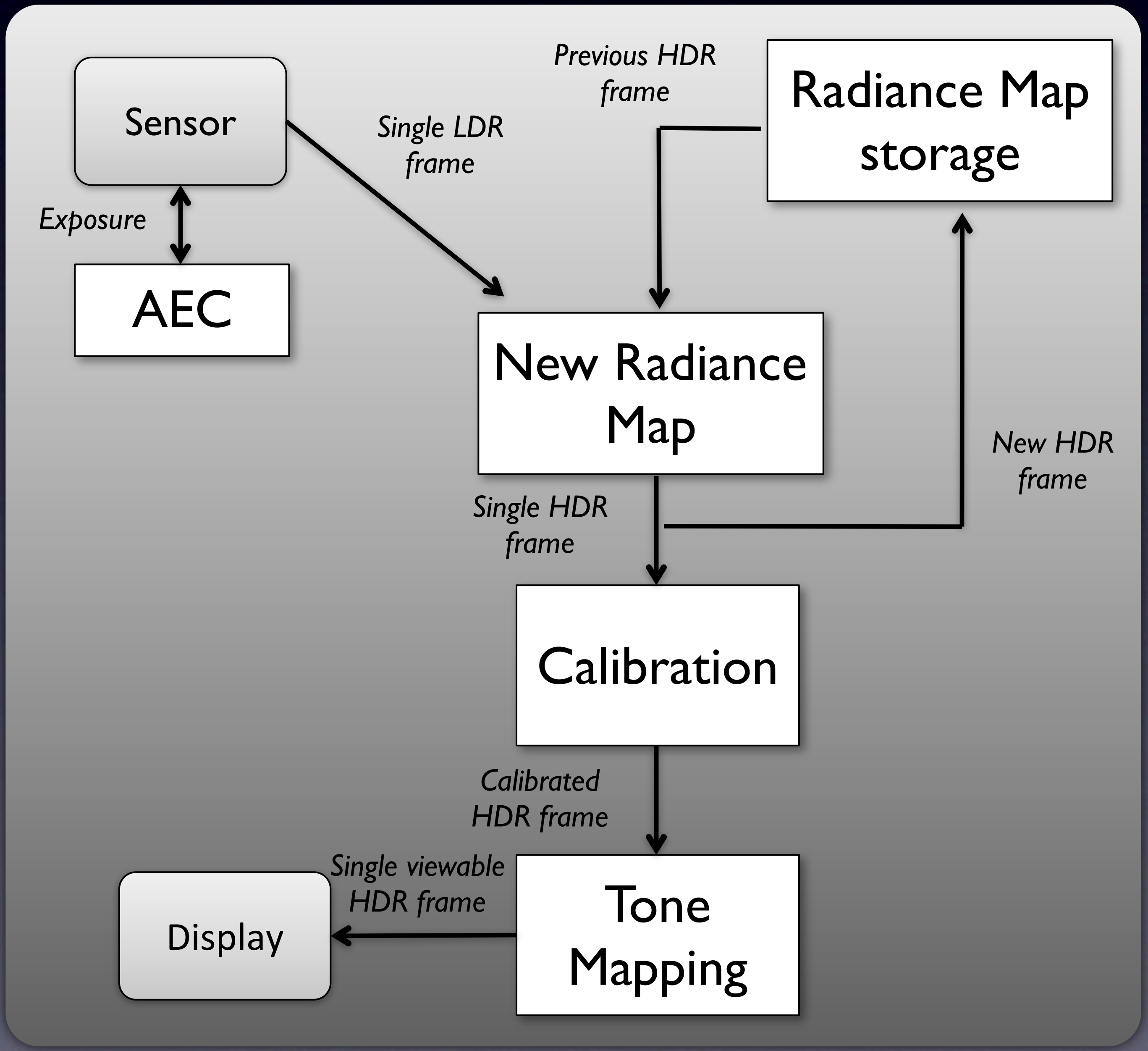


- Based on a ML507 development board from Xilinx
- Embeds a Virtex-5 FPGA
- Specific daughter card designed for the interconnection of the image sensor

Modified HDR Pipeline

- Simplification of the block diagram
- Realtime processing of the pixel flow





- Needs only one LDR frame
- Less memory storage

VHDL development

- Auto exposure control based on histograms and the number of saturated pixels
- First algorithm of radiance map based on Debevec's algorithm
- First algorithm of global tone mapping based on Reinhard's algorithm

Simulation results

HW implementation simulation

C++ simulation

Conclusion

- Dedicated platform for realtime HDR imaging
- Innovative algorithm pipeline operating on the pixels flow
- VHDL design of AEC, radiance map and tone mapping

To be done

- Hardware implementation of the full pipeline
- Development and optimization of new algorithms for radiance map and tone mapping
- Validation on real scenes

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