Radiance and HDR workshop 2025

Overview of LDR image merging algorithms

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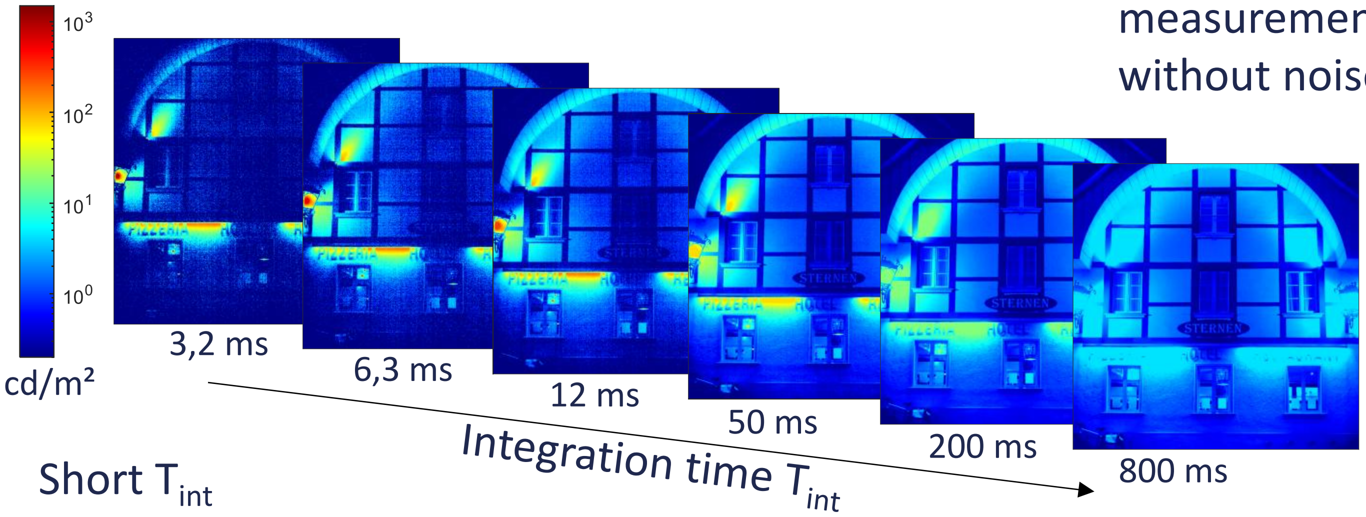
HDR merging algorithms

{HiDyn}

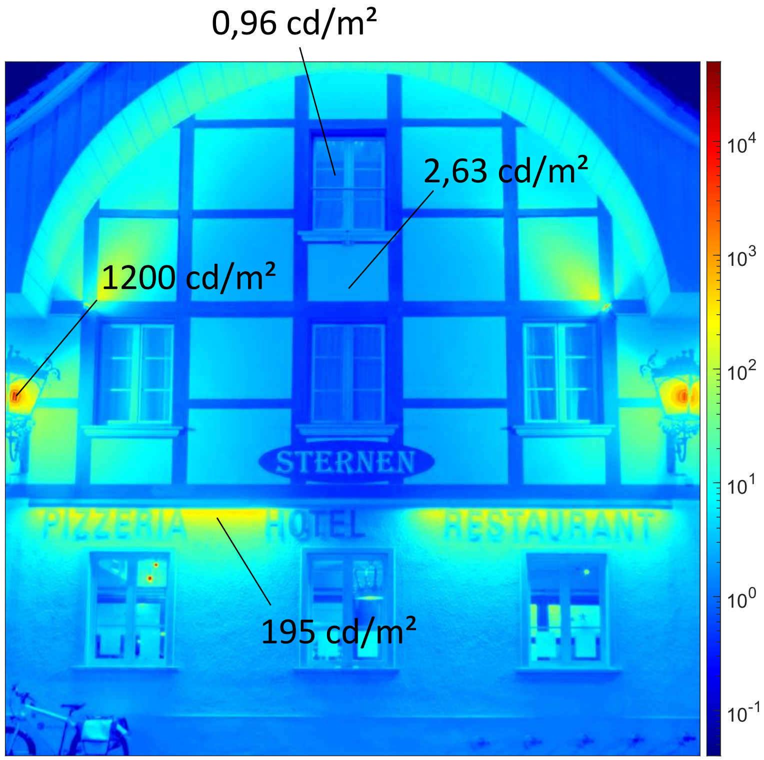
HDR = High Dynamic Range

Long T_{int}
→ for low luminance measurements without noise



Short T_{int}
→ for high luminance measurements without saturating

HDR merging (algorithm)



Luminance, cd/m²

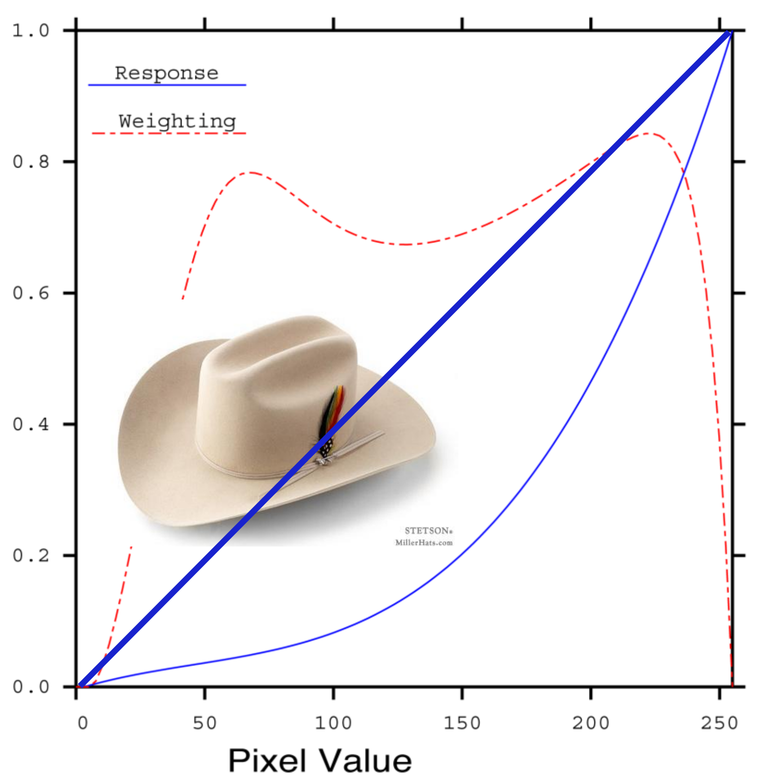
ILMD HDR

ILMD = Imaging Luminance Measurement Device

HDR from Multiple Exposures

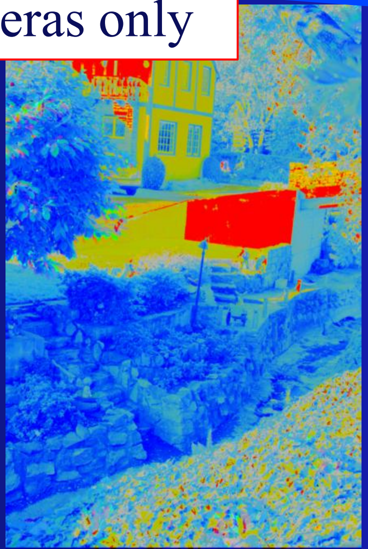
Input exposures:

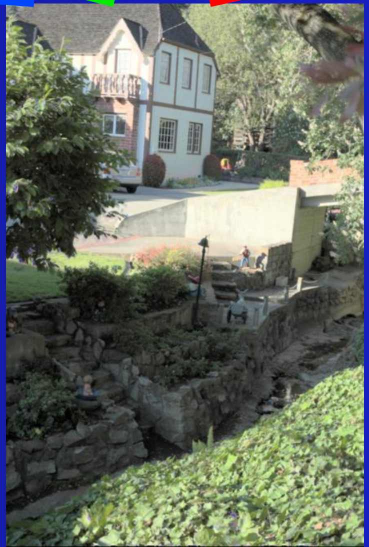
Camera response & weighting functions



LINEAR
cameras only

Input weights





Tone-mapped result

HDR merging algorithms

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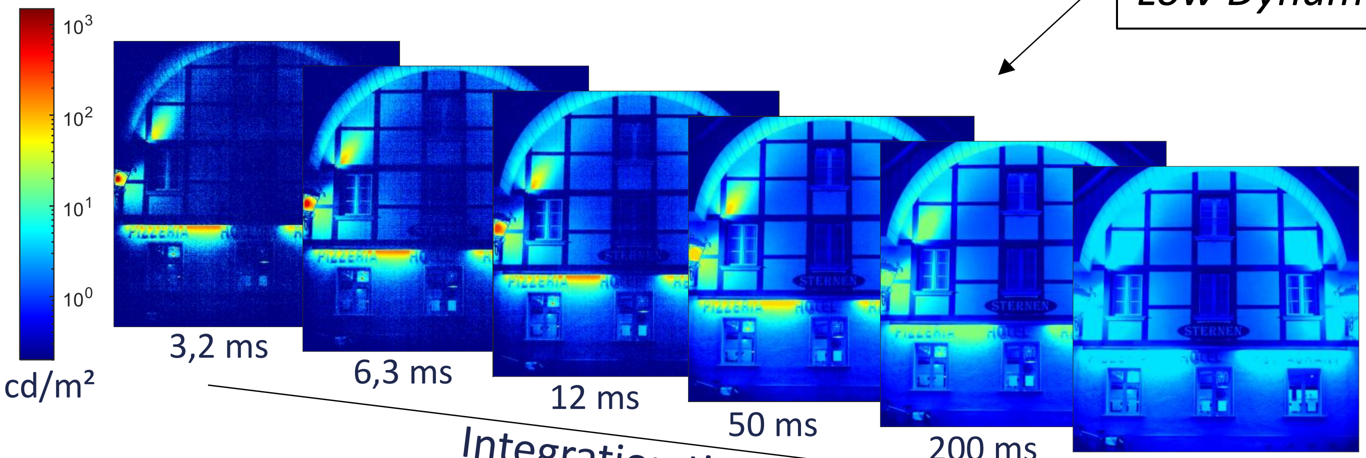
HDR = High Dynamic Range

LDR images
Low Dynamic Range

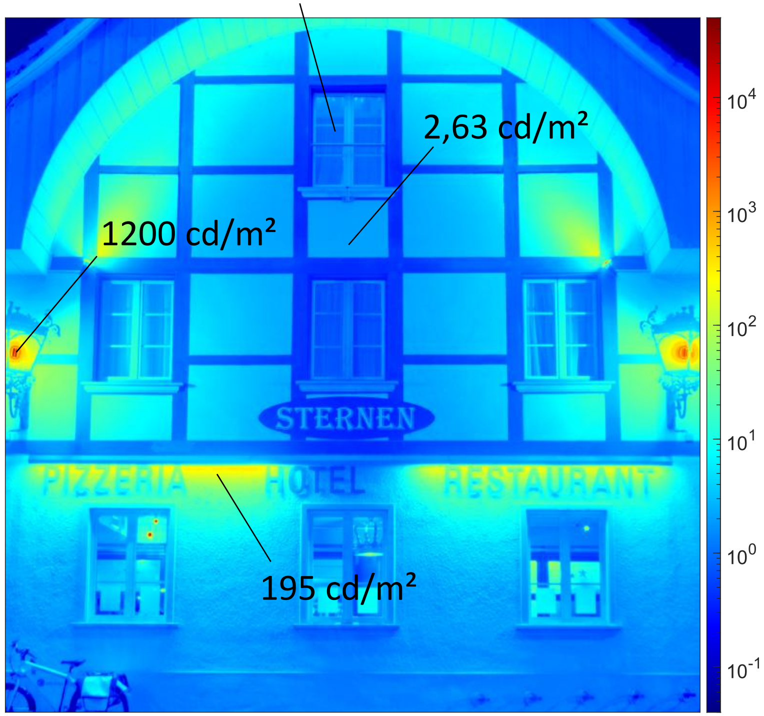


cd/m²

3,2 ms · 6,3 ms · 12 ms · 50 ms · 200 ms · 800 ms

Integration time T_{int}

HDR merging (algorithm)



0,96 cd/m²

2,63 cd/m²

1200 cd/m²

195 cd/m²

Luminance, cd/m²

ILMD HDR

ILMD = Imaging Luminance Measurement Device

HDR merging algorithms

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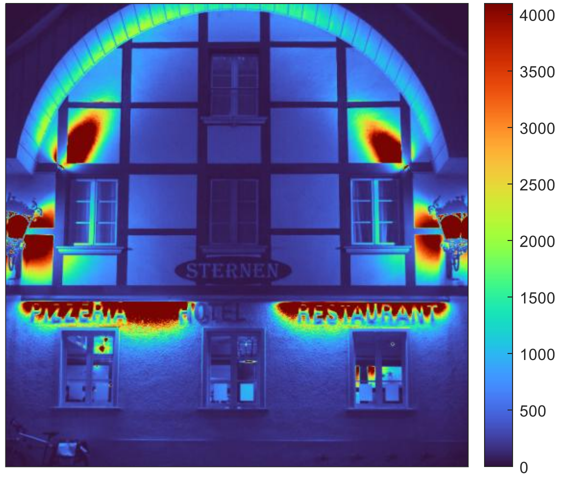
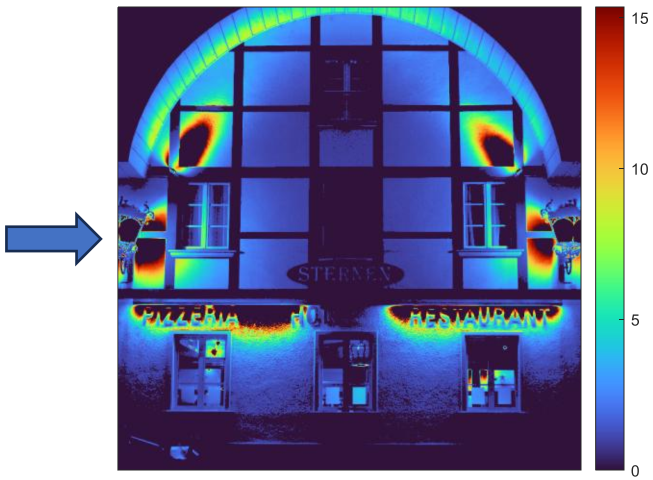
Valid for linear cameras only

Luminance estimation from a Low Dynamic Range (LDR) image:



RAW LDR image captured
at T_{int} = 200 ms
12-bits dynamic [0 – 4095]



Luminance map captured
at T_{int} = 200 ms

For each pixel

$$L_{\mathrm{LDR}} = \frac{1}{s_V} \cdot \frac{D - D_0}{t_{int}} + \varepsilon, \quad [\mathrm{cd/m^2}]$$

If the pixel is « well-exposed », i.e.,

$$D_{\min} \leq D \leq D_{\max} \leq D_{\mathrm{sat}}$$

D	is the value of the LDR pixel signal [counts];
D_0	is the associated dark signal [counts];
t_{int}	is the integration time [s];
s_V	is the luminous responsivity [$s^{-1} \cdot cd^{-1} \cdot m^2$];
ε	is the error

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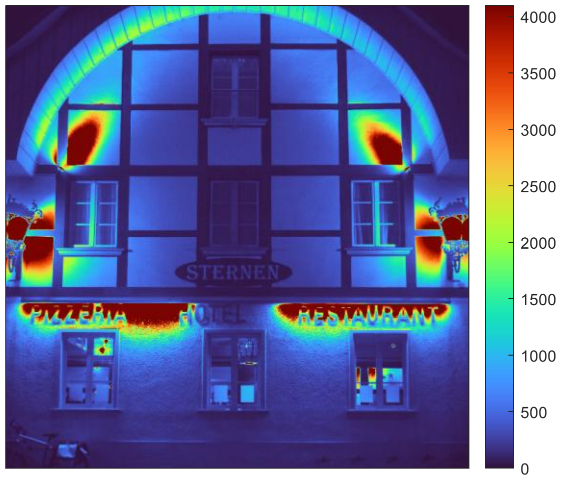
Luminance estimation from a Low Dynamic Range (LDR) image:

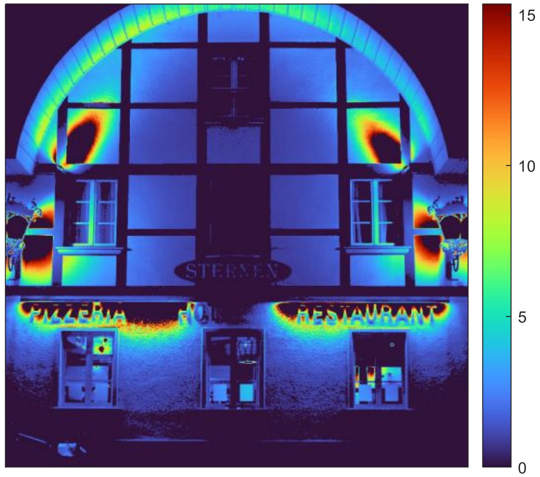
Valid for linear cameras only

Pixel value [counts]

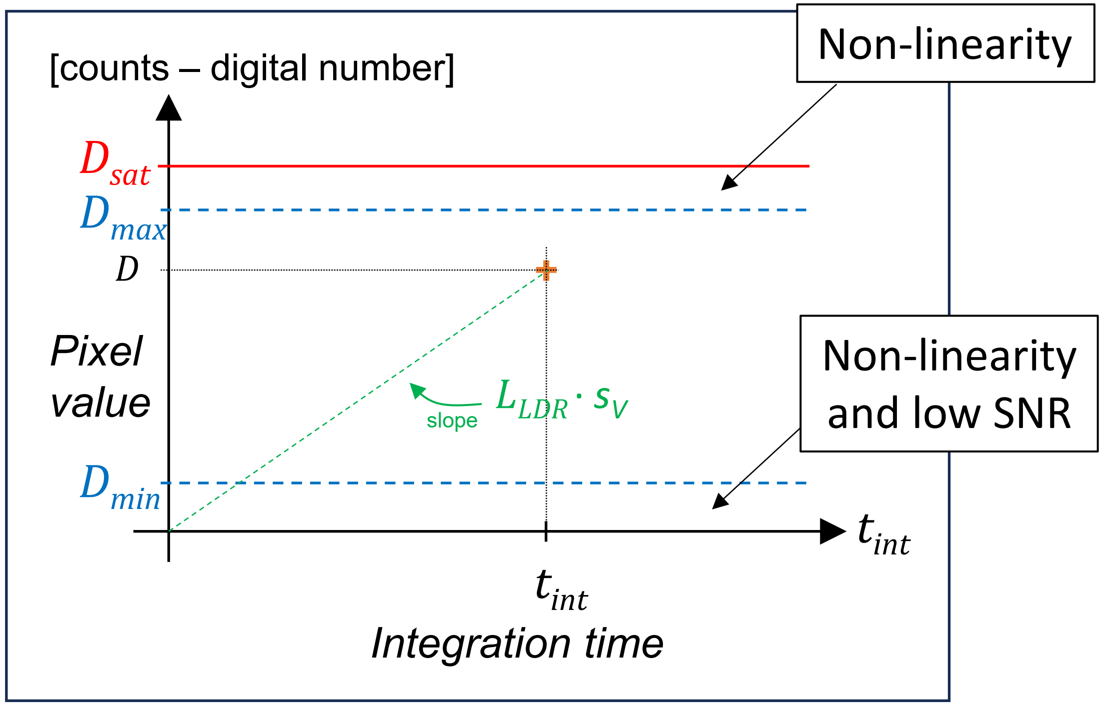


RAW LDR image captured
at T_{int} = 200 ms
12-bits dynamic [0 – 4095]

Luminance [cd/m²]



Luminance map captured
at T_{int} = 200 ms



$$L_{\mathrm{LDR}} = \frac{1}{s_V} \cdot \frac{D - D_0}{t_{int}} + \varepsilon,$$

$$D_{\min} \leq D \leq D_{\max} \leq D_{\mathrm{sat}}$$

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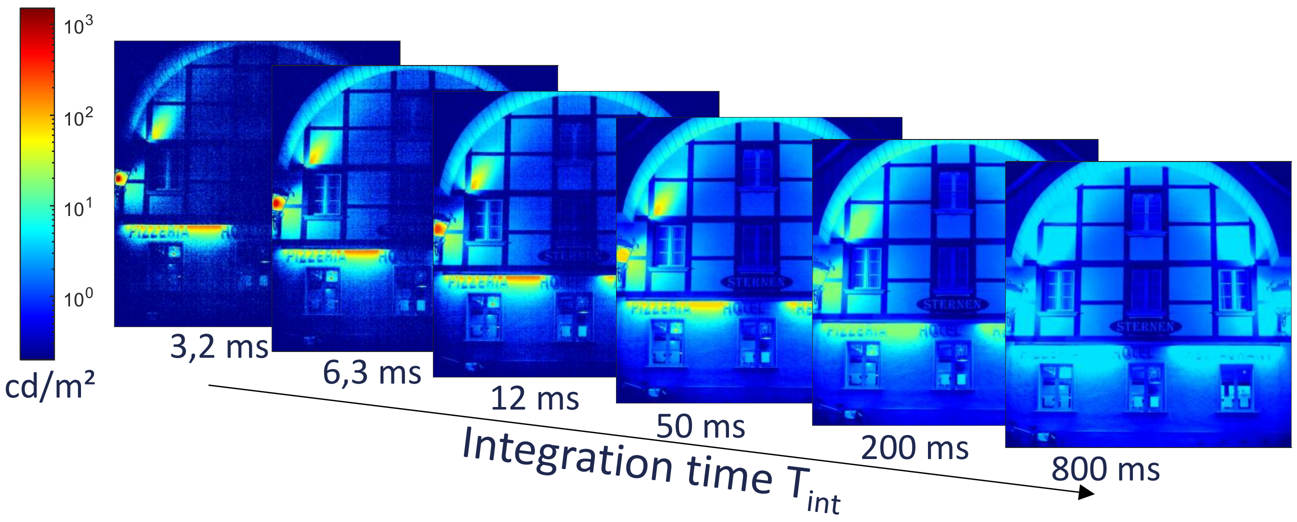
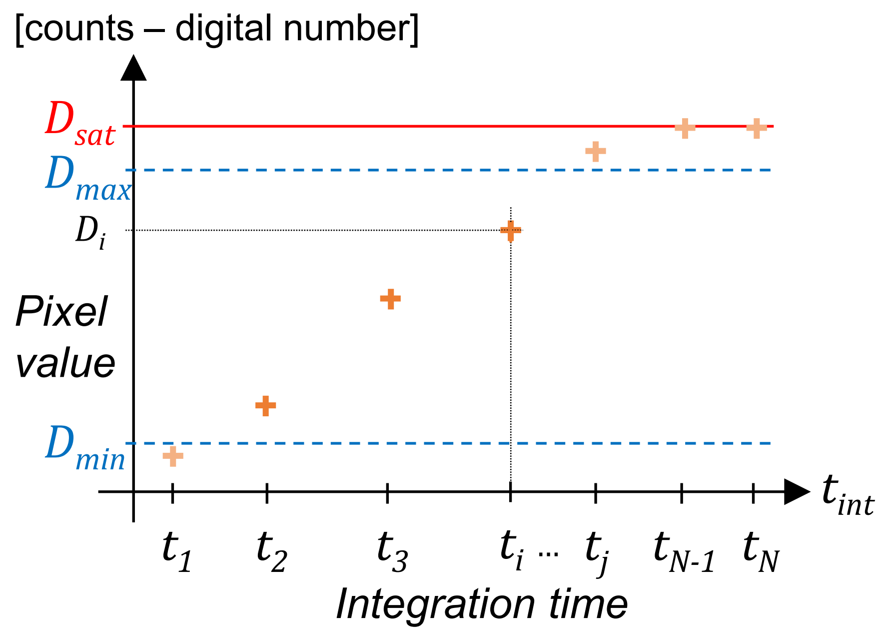
Valid for linear cameras only

Luminance estimation from a series of LDR images:





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Luminance estimation from a series of LDR images:

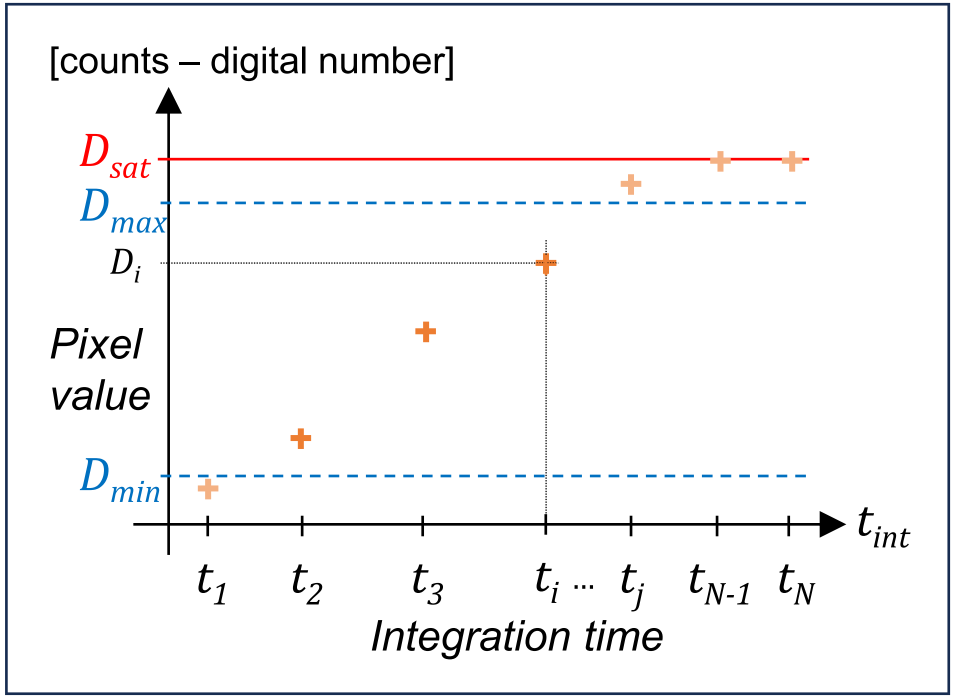
Valid for linear cameras only

For each pixel of image *i*

$$L_i = \frac{1}{s_V} \cdot \frac{D_i - D_{0,i}}{t_i} + \varepsilon_i \,, \quad \text{[cd/m²]}$$

If the pixel is « well-exposed », i.e.,

$$D_{\min} \leq D_i \leq D_{\max} \leq D_{\text{sat}}$$



D	is the value of the LDR pixel signal [counts];
D_0	is the associated dark signal [counts];
t_{int}	is the integration time [s];
s_V	is the luminous responsivity [$s^{-1} \cdot cd^{-1} \cdot m^2$];
ε_i	is the error

HDR merging algorithms

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Valid for linear cameras only

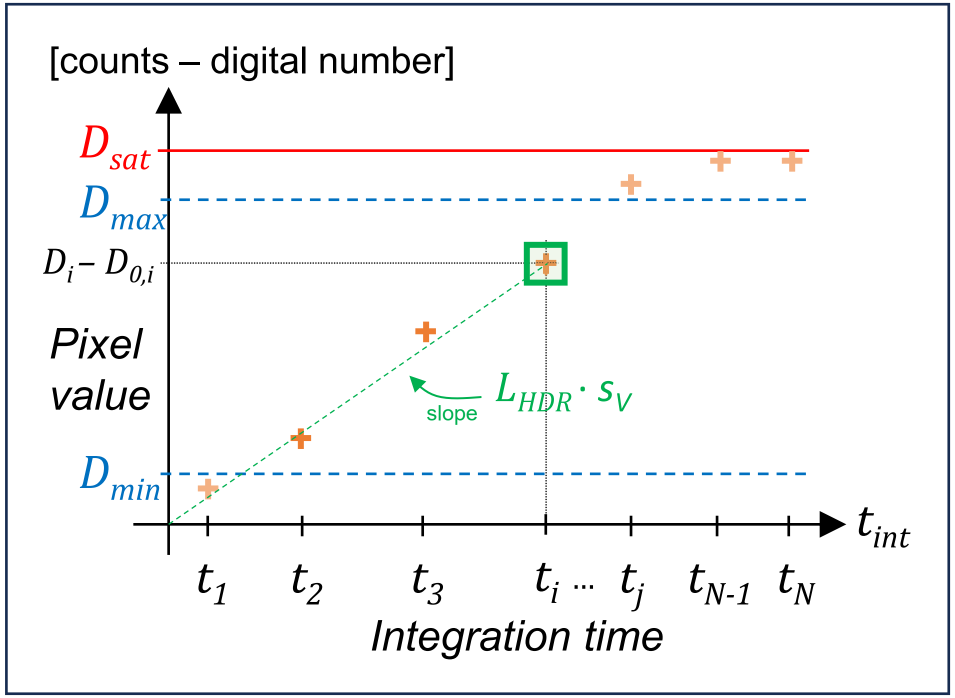
"Best exposure" algorithm:

For each pixel

$$L_{HDR} = \frac{1}{s_V} \cdot \frac{D_i - D_{0,i}}{t_i}, \qquad [\text{cd/m}^2]$$

with

$$t_i = \max\{t_i \text{ such that } D_{\min} \leq D_i \leq D_{\max}\}$$



D_i is the value of the LDR pixel signal [counts];
$D_{0,i}$ is the associated dark signal [counts];
t_i is the integration time [s];
s_V is the luminous responsivity [$s^{-1} \cdot cd^{-1} \cdot m^2$];

HDR merging algorithms

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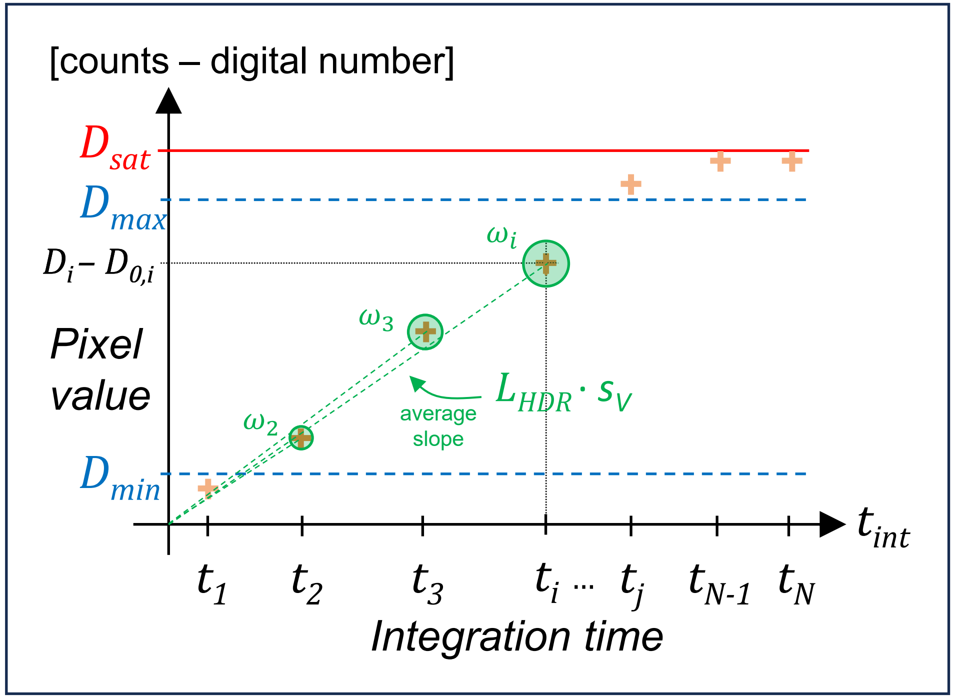
“Weighted-average” algorithm:

Valid for linear cameras only

For each pixel

$$L_{HDR} = \frac{1}{s_V} \cdot \frac{\sum_{i=1}^{N} q_i\, w_i\, \frac{D_i - D_{0,i}}{t_i}}{\sum_{i=1}^{N} q_i\, w_i}, \text{ [cd/m²]}$$

$$\text{with } q_i = \begin{cases} 1 & (D_{\min} \le D_i \le D_{\max}) \\ 0 & \text{otherwise} \end{cases}$$



D_i is the value of the LDR pixel signal [counts];
$D_{0,i}$ is the associated dark signal [counts];
t_i is the integration time [s];
s_V is the luminous responsivity [$s^{-1} \cdot cd^{-1} \cdot m^2$];
w_i is the weight associated with the pixel

Example of weight function: $w_i = t_i$

HDR merging algorithms

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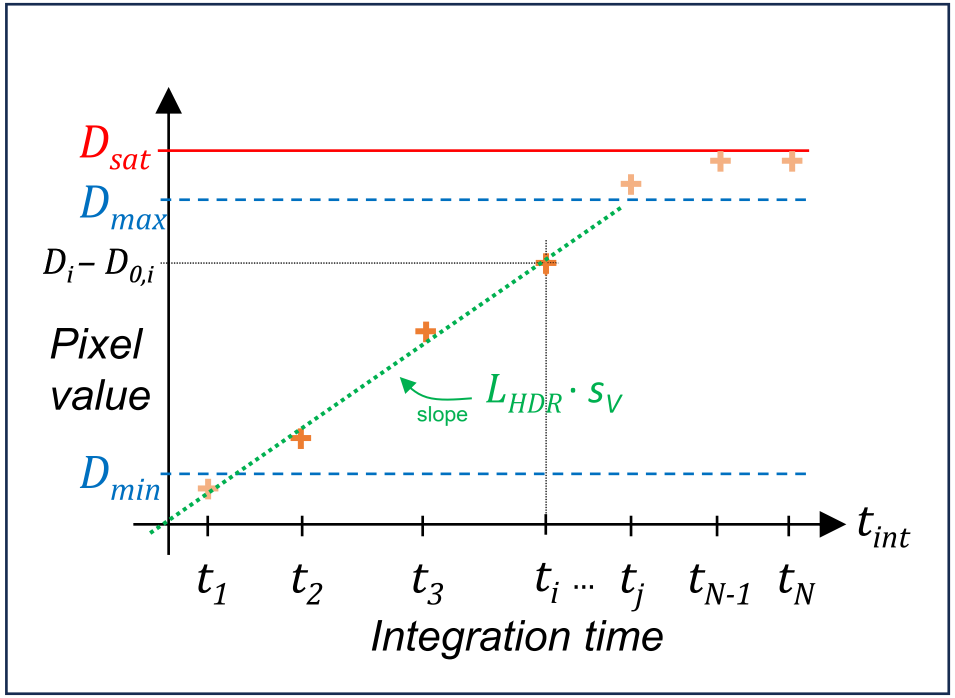
Valid for linear cameras only

"Linear regression" algorithm:

For each pixel

$$L_{\mathrm{HDR}} = \frac{1}{s_V} \frac{\sum_{i=1}^{N} q_i \cdot \sum_{i=1}^{N} q_i\, t_i \,(D_i - D_{0,i}) - \sum_{i=1}^{N} q_i\, t_i \cdot \sum_{i=1}^{N} q_i \,(D_i - D_{0,i})}{\sum_{i=1}^{N} q_i \cdot \sum_{i=1}^{N} q_i\, t_i^2 - \left(\sum_{i=1}^{N} q_i\, t_i\right)^2}$$

$$\text{with } q_i = \begin{cases} 1 & (D_{\min} \le D_i \le D_{\max}) \\ 0 & \text{otherwise} \end{cases}$$



D_i is the value of the LDR pixel signal [counts];
$D_{0,i}$ is the associated dark signal [counts];
t_i is the integration time [s];
s_V is the luminous responsivity [$s^{-1} \cdot cd^{-1} \cdot m^2$];

HDR merging algorithms

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Valid for linear cameras only

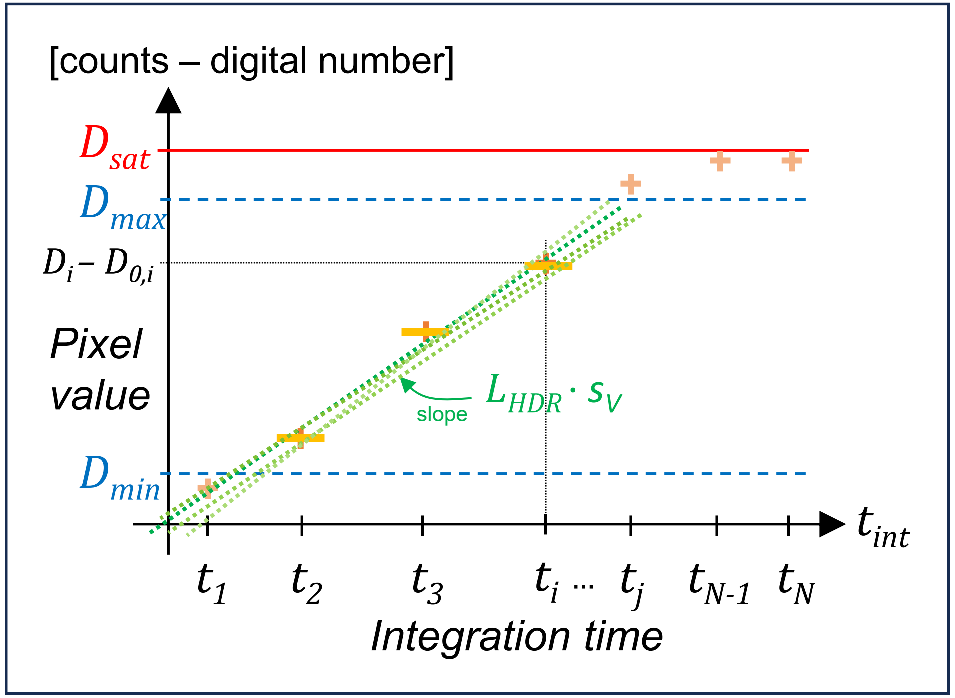
Parameters with a high impact on the calculated luminance

- Accurate knowledge of the exposure value (e.g. integration time) is required

$$L_i = \frac{1}{s_V} \cdot \frac{D_i - D_{0,i}}{t_i} + \varepsilon_i \ ,$$

If the pixel is « well-exposed », i.e.,

$$D_{\min} \leq D_i \leq D_{\max} \leq D_{\text{sat}}$$



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Valid for linear cameras only

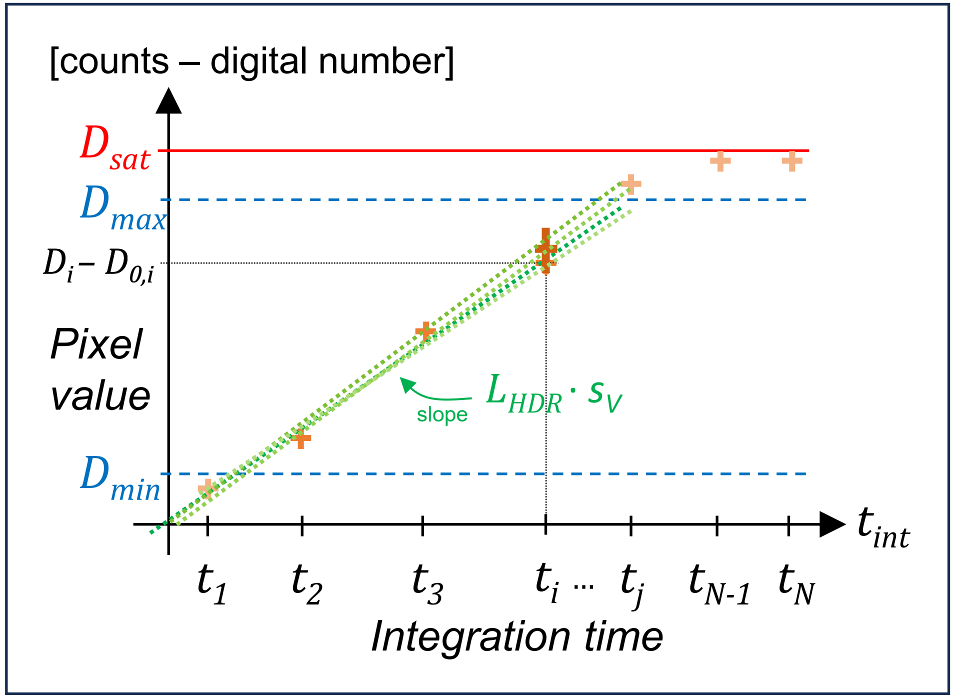
Parameters with a high impact on the calculated luminance

- Linearity of the camera (or knowledge of the camera response function) is crucial

$$L_i = \frac{1}{s_V} \cdot \frac{D_i - D_{0,i}}{t_i} + \varepsilon_i \ ,$$

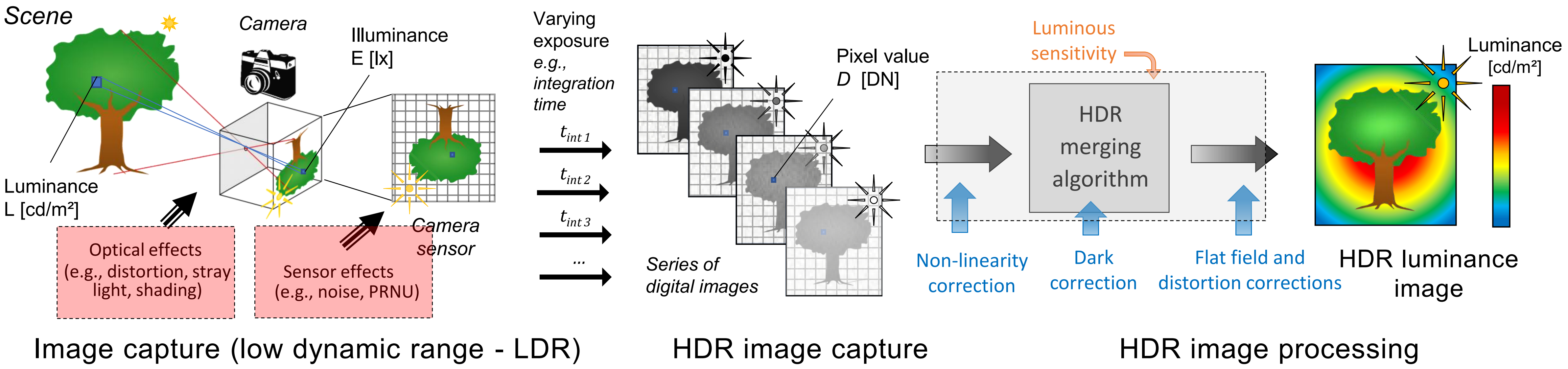
If the pixel is « well-exposed », i.e.,

$$D_{\min} \leq D_i \leq D_{\max} \leq D_{\mathrm{sat}}$$



HDR merging algorithms

Workflow of HDR image acquisition and processing for luminance measurement



HDR merging algorithms

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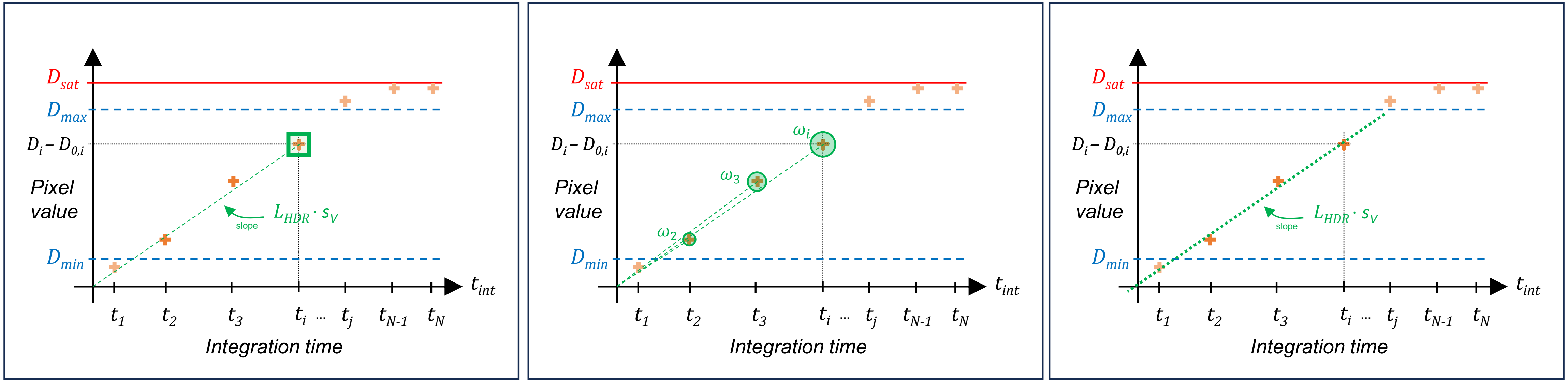
- HDR merging algorithms have simple mathematical expressions
- Good non-linearity correction before merging is key to an accurate reconstruction
- The algorithm parameters defining the well-exposed pixel have significant impact



"Best exposure" algorithm *"Weighted average" algorithm* *"Linear regression" algorithm*

Valid for linear cameras only