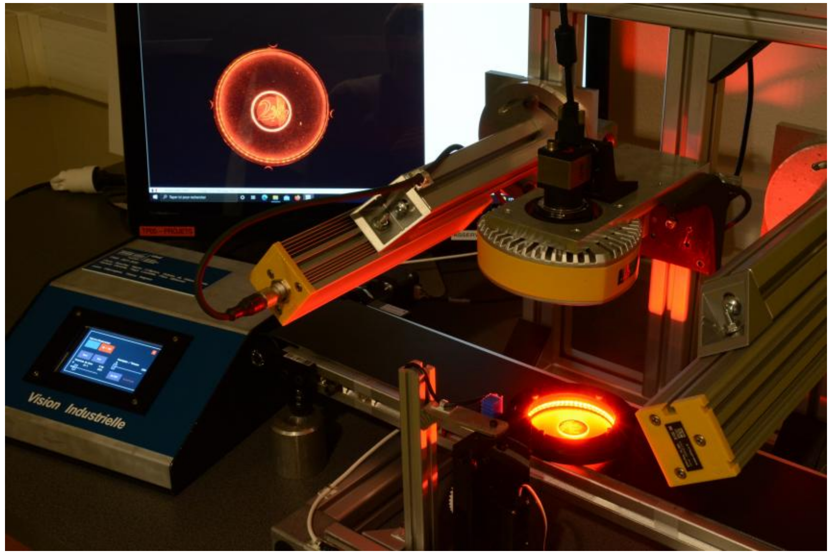
INSTITUT d'OPTIQUE GRADUATE SCHOOL

LEnsE Laboratoire d'Enseignement Expérimental

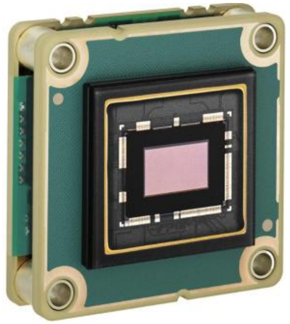
SC 19 – Machine Vision

Cameras and Interfaces

Julien VILLEMEJANE



IDS Sensor



Basler Sensor / Mouser

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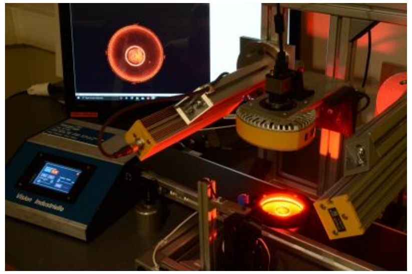

SC19 – Cameras and Interfaces

- At the end of this training, the learners will be able to:

Characterize a camera

Resolution, bit depth

Exposure Time, Black level

Digital Image, data transfer

LEnsE.TECH

https://iogs-lense-training.github.io/image-processing/

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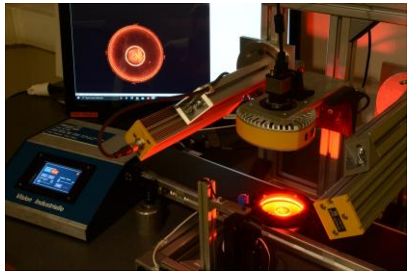
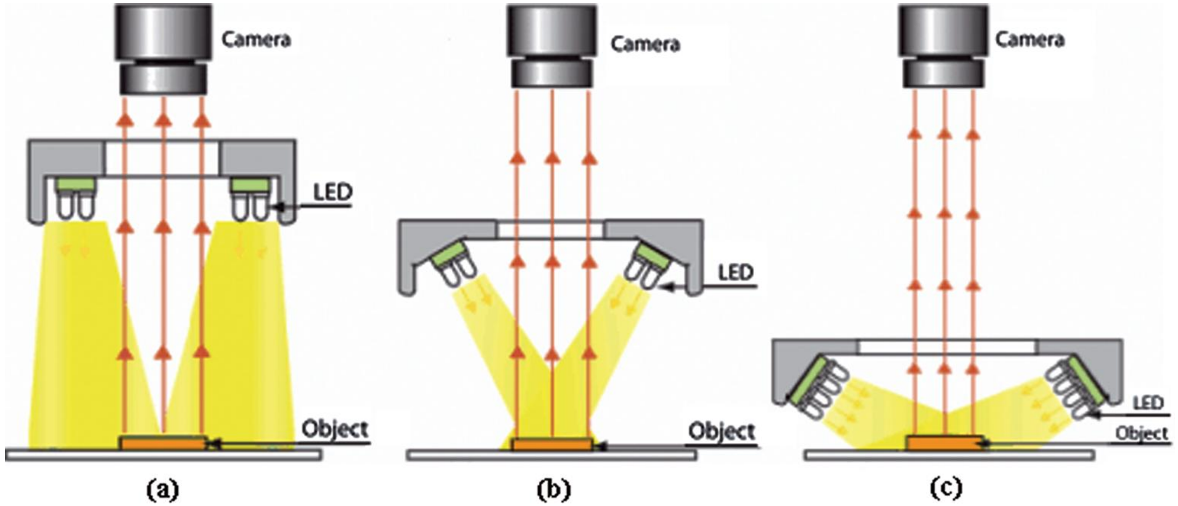


SC19 – Cameras and Interfaces

Camera in a machine vision chain



Dong, Jing-Tao & lu, rs & Shi, Yan-Qiong & Xia, Rui-Xue & Li, Qi & Xu, Yan. (2011). Optical design of color light-emitting diode ring light for machine vision inspection. Optical Engineering - OPT ENG. 50. 10.1117/1.3567053.

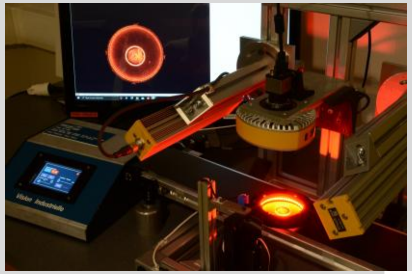
Camera

Device that transforms a **light flux** into a **measurable electrical signal**

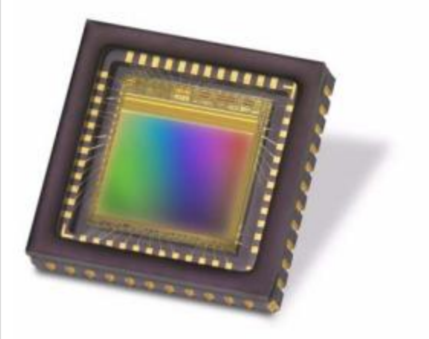
Light flux → Camera → Electrical signal

SC19 – Cameras and Interfaces

Anatomy of an IDS sensor



IDS UI-1240SE-C-HQ



e2v sensor EV76C560ACT

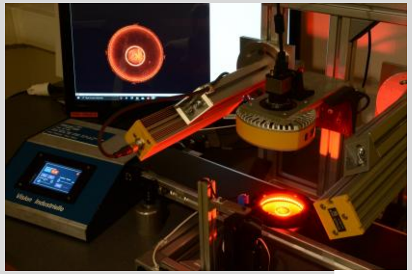
Capteur	
Type de capteur	CMOS Couleur
Mode d'obturateur	Global / Rolling / Global Start
Caractéristique du capteur	Linéaire
Méthode de lecture du capteur	Progressive scan
Classe de pixels	1.3 MP
Résolution	1,31 Mpx
Résolution (h x v)	1280 x 1024 Pixel
Rapport hauteur/largeur	5:4
CAN	10 bit
Profondeur des couleurs (caméra)	8 bit
Classe de capteur optique	1/1,8""
Surface optique	6,784 mm x 5,427 mm)
Diagonale du capteur optique	8,69 mm (1/1,84")
Taille de pixel	5,3 µm
Fabricant	e2v
Désignation du capteur	EV76C560ACT
Amplification (complet/RVB)	

Capteur EV76C560 Typical electro-optical performance @ 25°C and 65°C, nominal pixel clock

Parameter		**Unit**	**Typical value**	
Sensor characteristics	Resolution	pixels	1280 (H) × 1024 (V)	
	Image size	mm inches	6.9 (H) × 5.5 (V) - 8.7 (diagonal) ≈ 1/1.8	
	Pixel size (square)	µm	5.3 × 5.3	
	Aspect ratio		5 / 4	
	Max frame rate	fps	60 @ full format	
	Pixel rate	Mpixels / s	90 -> 120	
	Bit depth	bits	10	
Pixel performance			**@ 25°C**	**@ 65°C**
	Dynamic range	dB	>62	>57
	Qsat	ke-	12	
	SNR Max	dB	41	39
	MTF at Nyquist, λ=550 nm	%	50	
	Dark signal (1)	LSB_{10}/s	24	420
	DSNU(1)	LSB_{10}/s	6	116
	PRNU (2) (RMS)	%	<1	
	Responsivity (3)	LSB_{10}/(Lux.s)	6600	
Electrical interface	Power supplies	V	3.3 & 1.8	
	Power consumption: Functional (4) Standby	mW µW	< 200 mW 180	

Resolution
Sensibility
Noise Performance
Size / Form factor
Lens compatibility
Shutter Type

Interface



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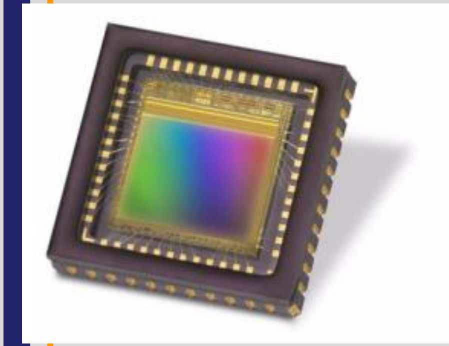
Main charateristics of the sensor



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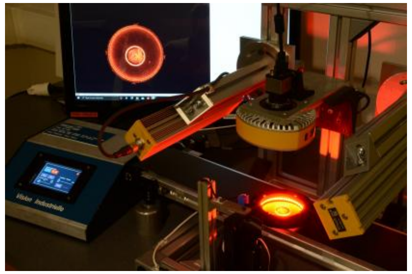
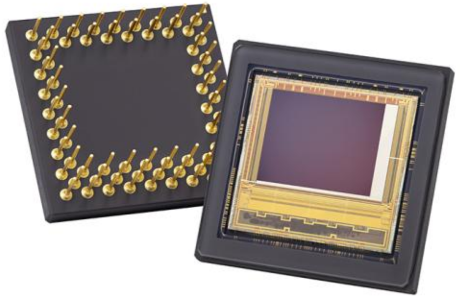
	Power consumption: Functional [(4)] Standby	mW µW	< 200 mW 180	

1. Min gain, 10 bits.
2. Measured @ Vsat/2, min gain.
3. 3200K, window with AR coating, IR cutoff filter BG38 2 mm.
4. @ 60 fps, full format, with 10 pF on each output.



SC19 – Cameras and Interfaces

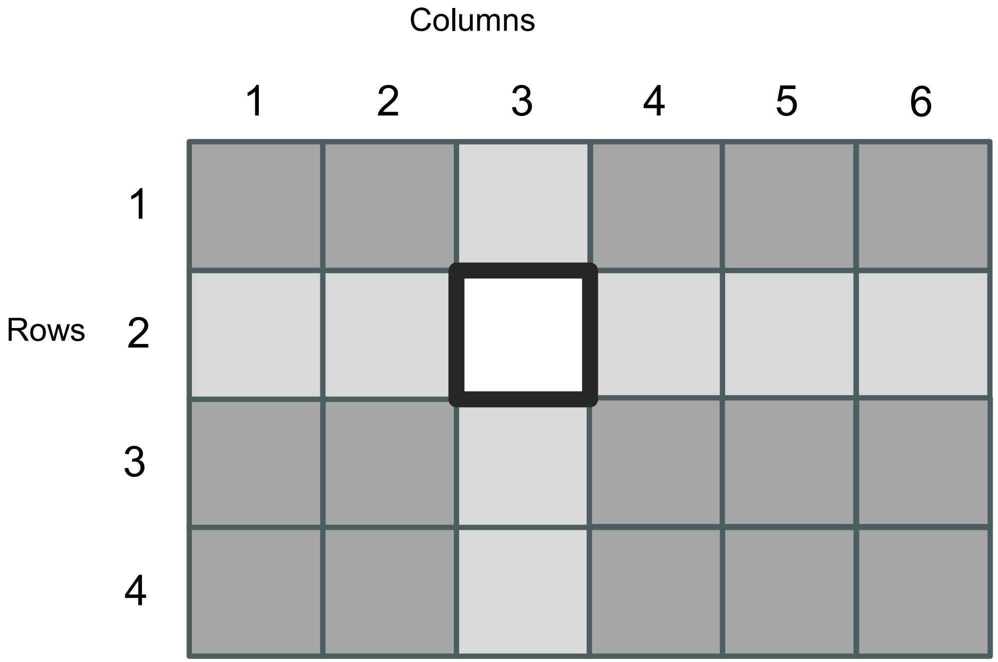
Camera / Array of small sensors

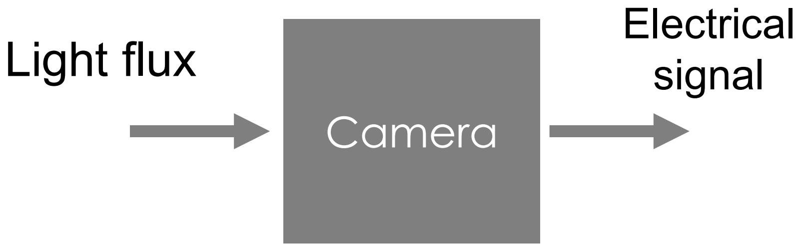


https://imaging.teledyne-e2v.com/products/2d-cmos-image-sensors/onyxmax/

Camera

Device that transforms a **light flux** into a **measurable electrical signal**





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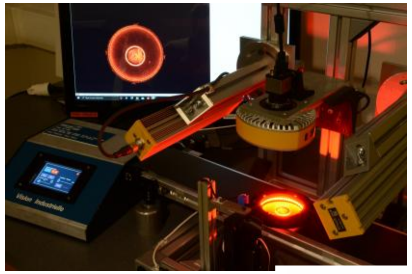
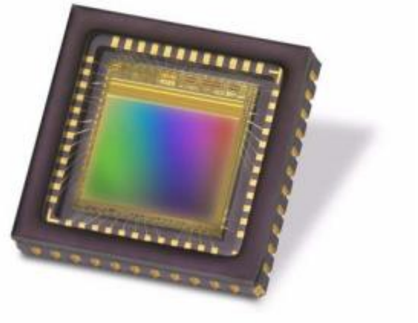
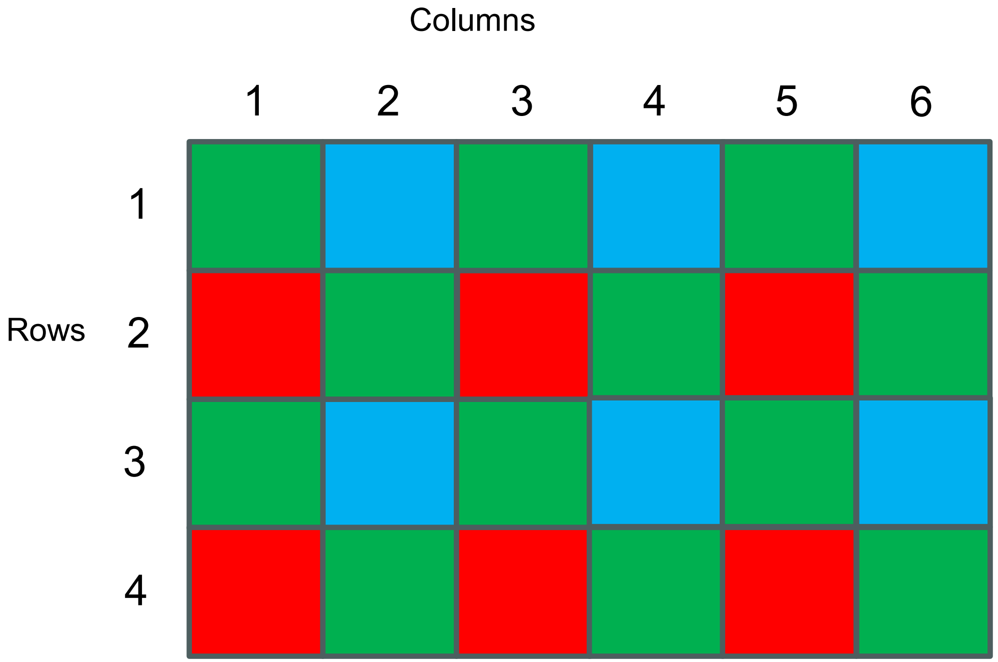


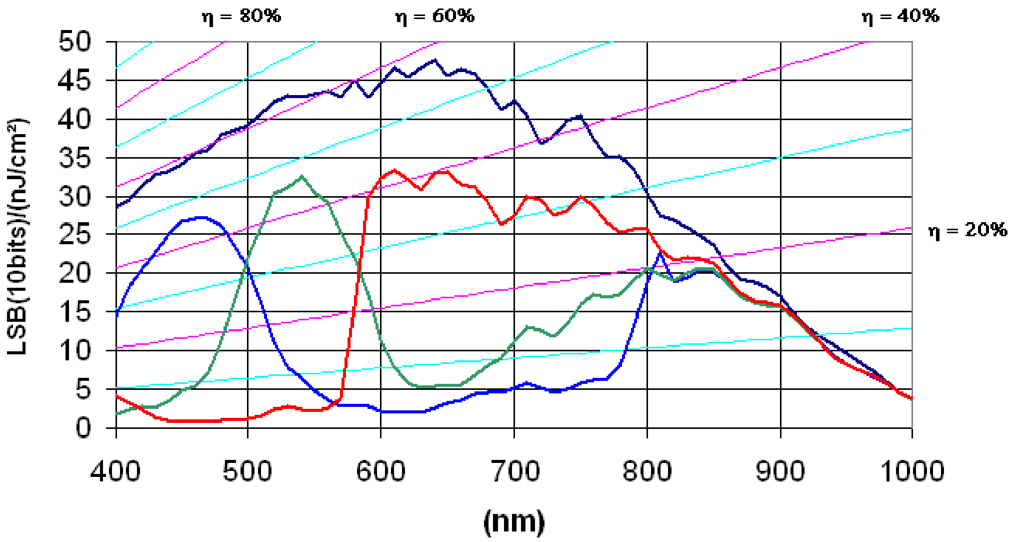
SC19 – Cameras and Interfaces

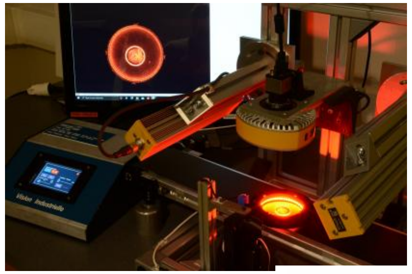
Camera / Bayer filter for color sensors



e2v sensor EV76C560ACT

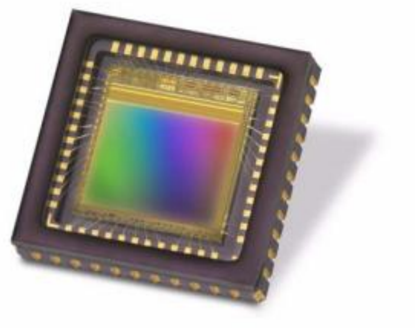




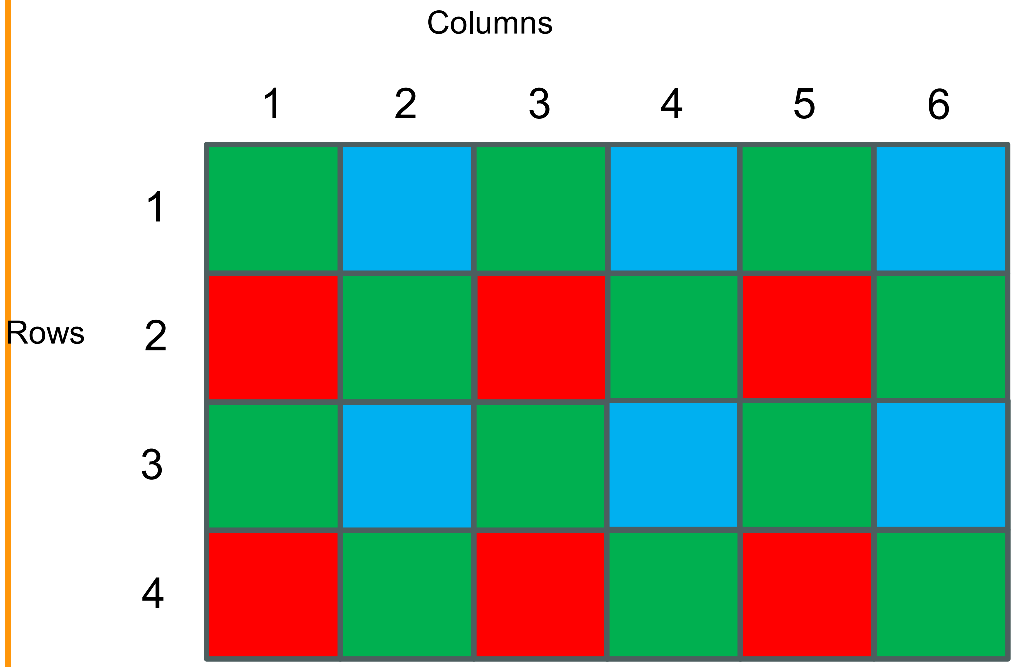


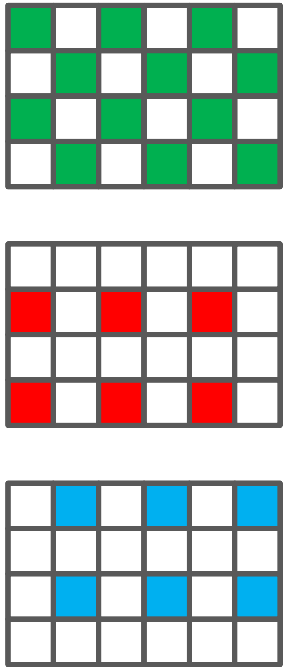
SC19 – Cameras and Interfaces

Camera / Bayer filter for color sensors



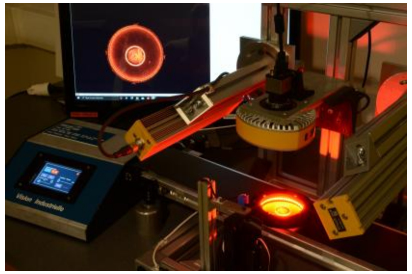
e2v sensor EV76C560ACT

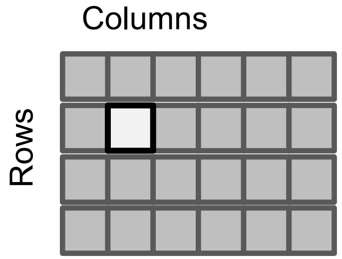


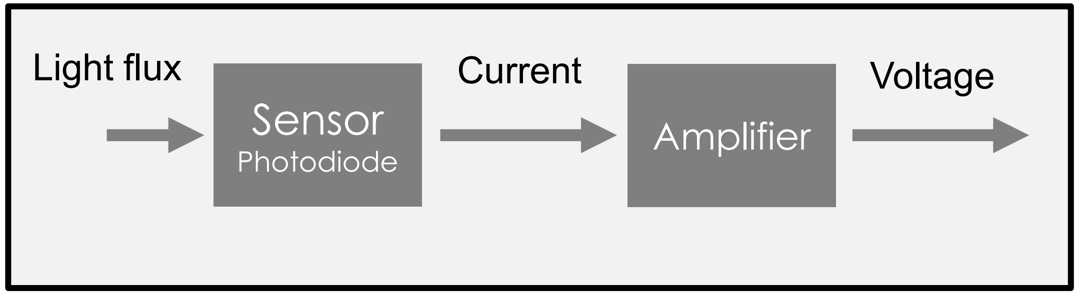


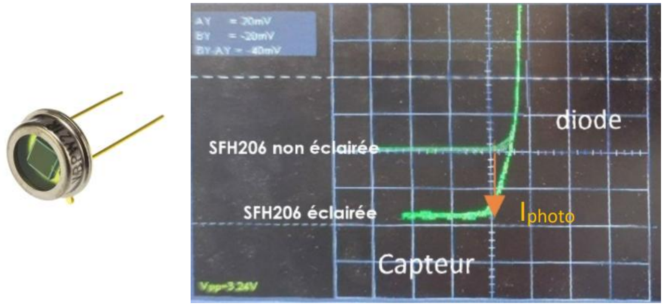
SC19 – Cameras and Interfaces

Camera / Inside a pixel



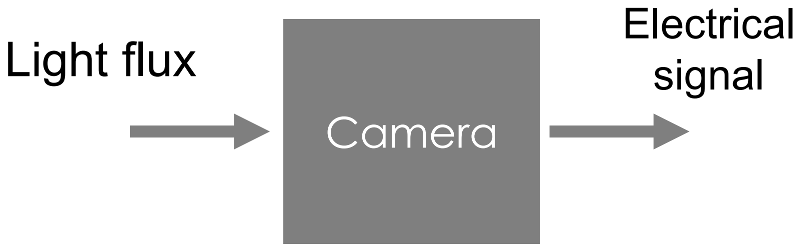






Camera

Device that transforms a **light flux** into a **measurable electrical signal**



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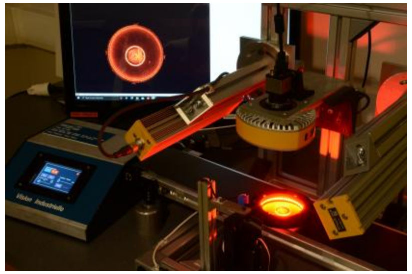
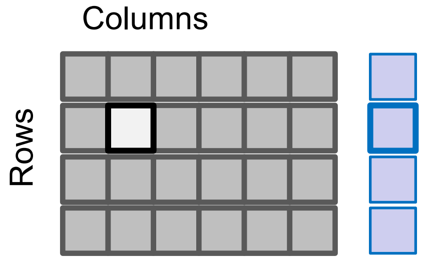
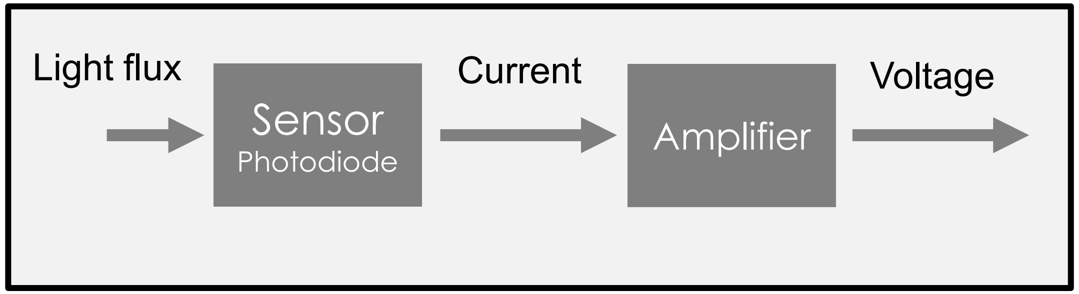
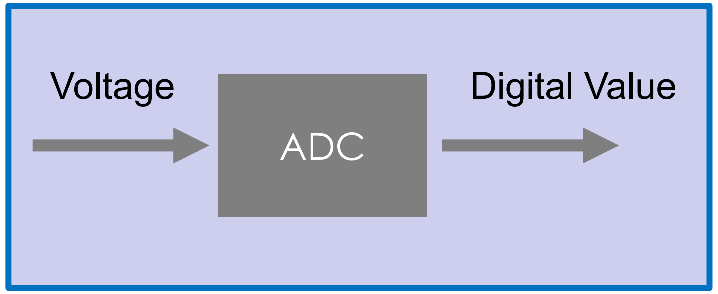


SC19 – Cameras and Interfaces

Camera / From analog to digital signal

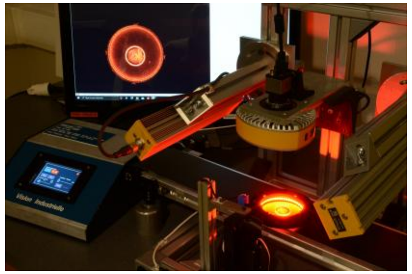






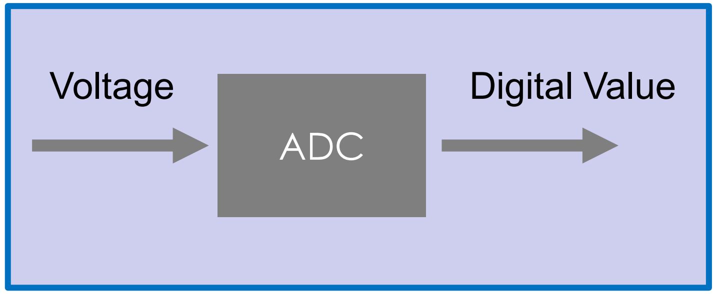
Digital Camera

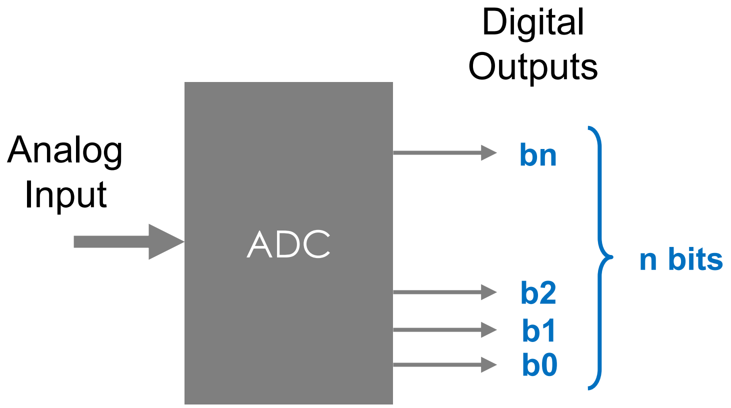
Device that transforms an array of **light flux sensors** into **digital data** called pixels



SC19 – Cameras and Interfaces

How an Analog to Digital Converter works ?



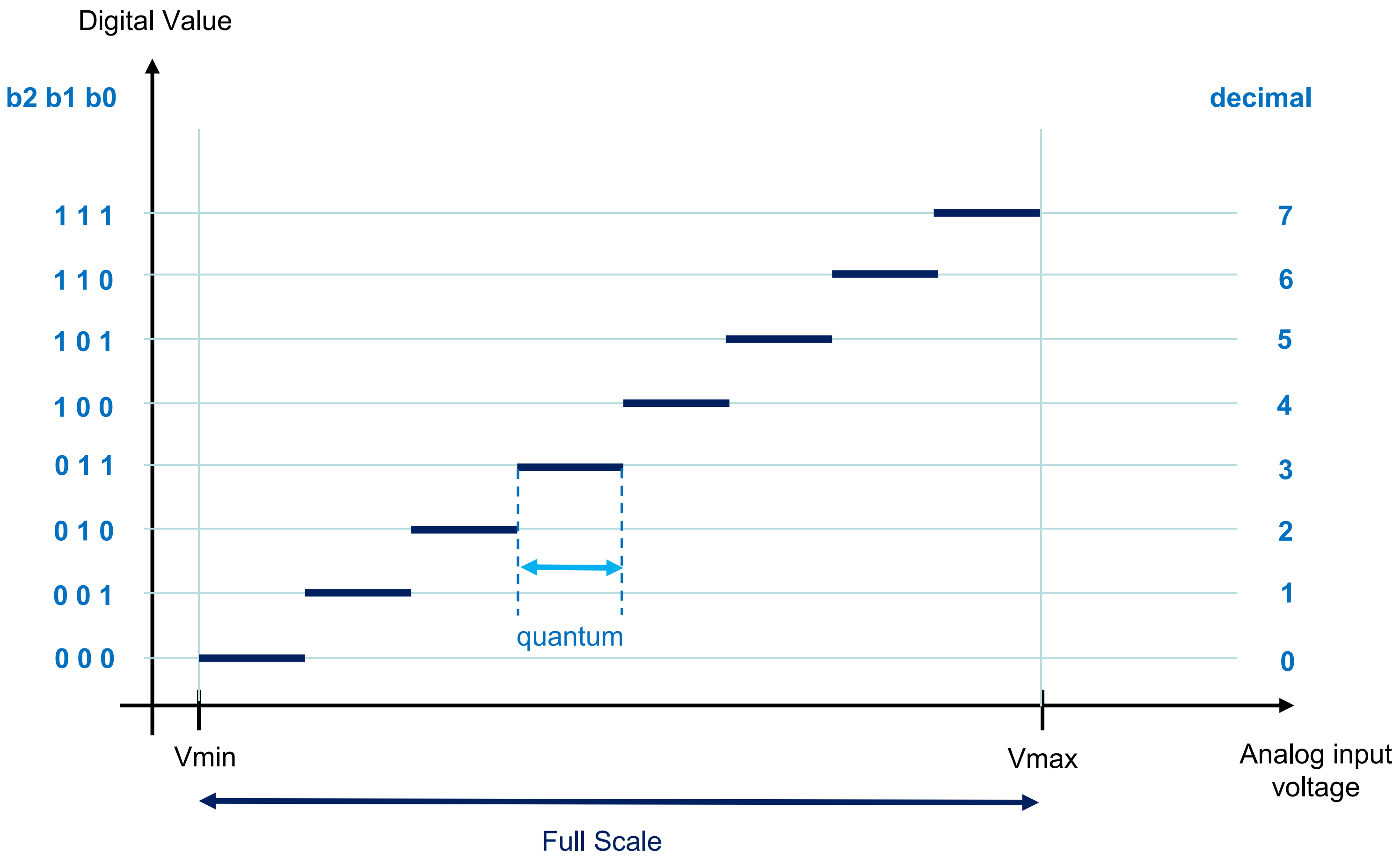


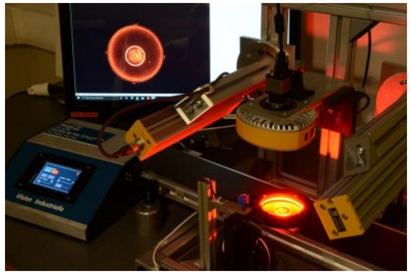
Each bit can have one of two values: **0** or **1**.

The **number of different values** that can be represented by **n bits** is **2^n**.

Example for n = 3 bits

Quantization

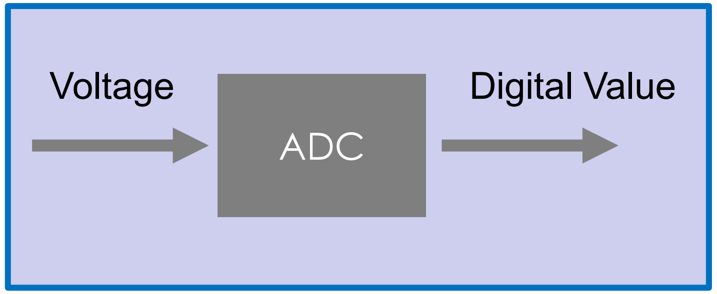


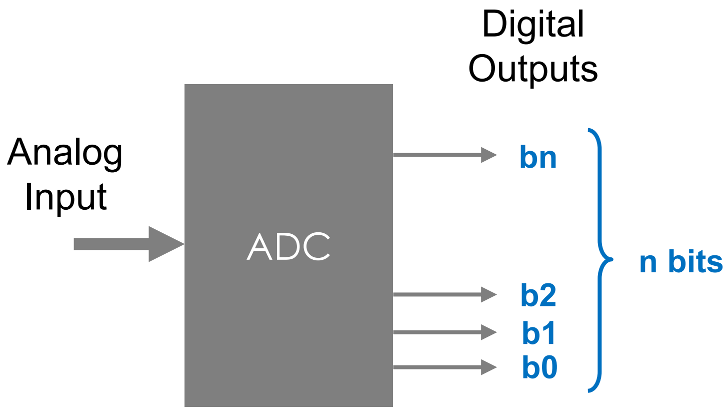


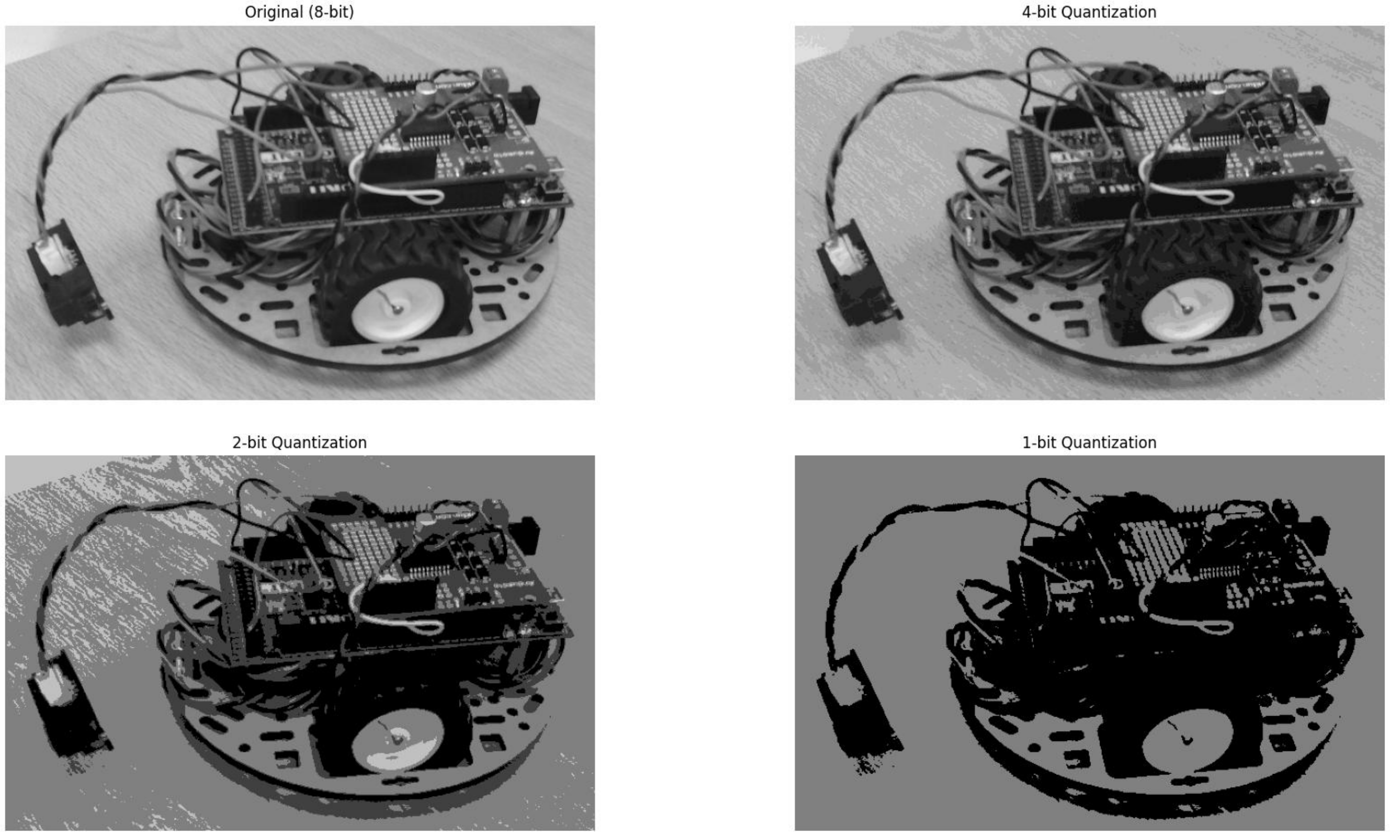
SC19 – Cameras and Interfaces

Sampling and quantization of an image

Quantization







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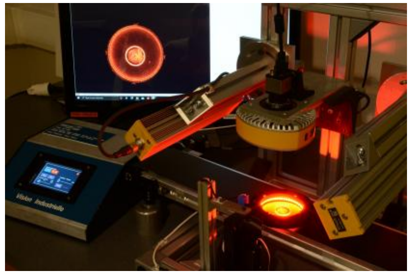
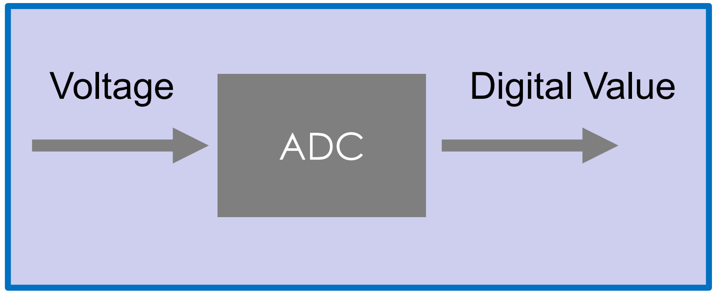


SC19 – Cameras and Interfaces

Sampling and quantization of an image



Sampling theorem

Nyquist–Shannon sampling theorem

The sampling frequency must be equal to or **greater than twice** the frequency associated with the finest detail in the image (edges).

With a grid spacing of ***d*** *, a periodic component with a period higher than* ***2.d*** *can be reconstructed.*

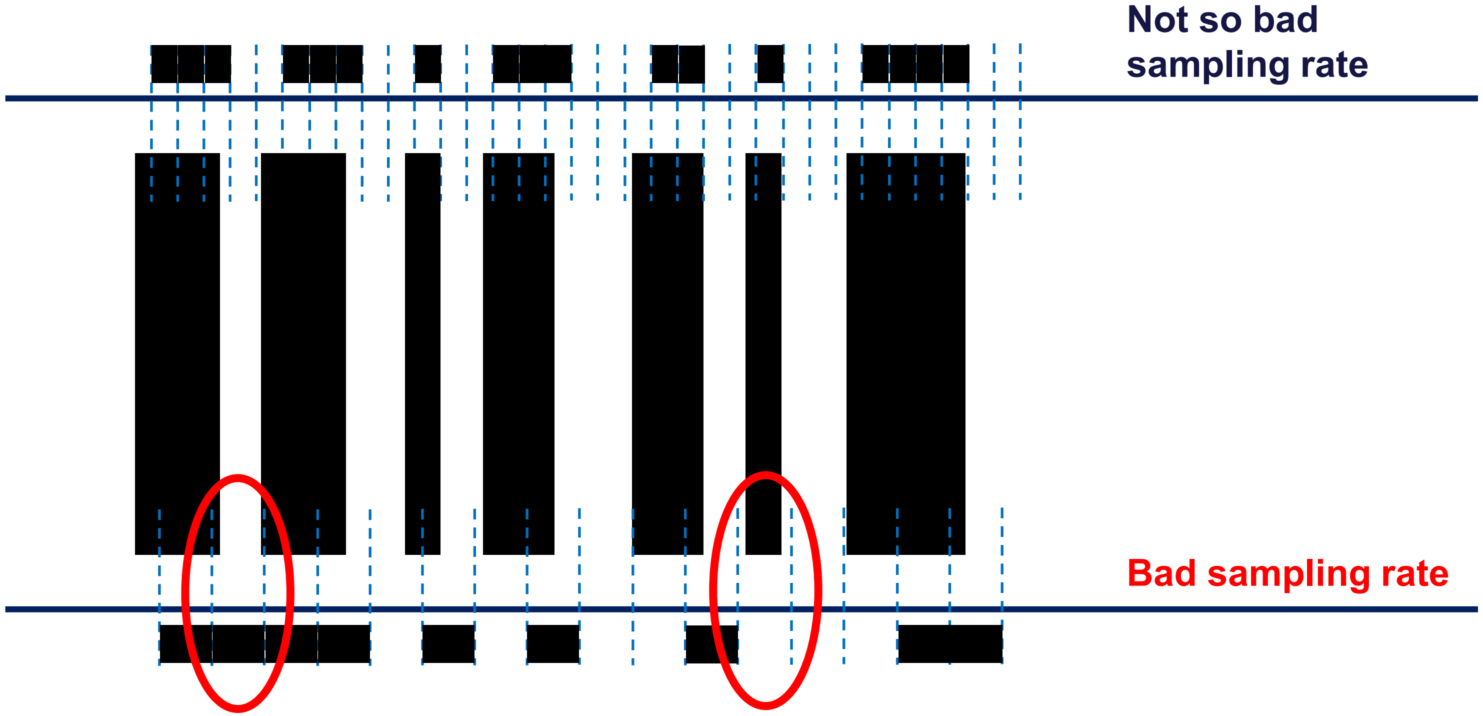
Sampling

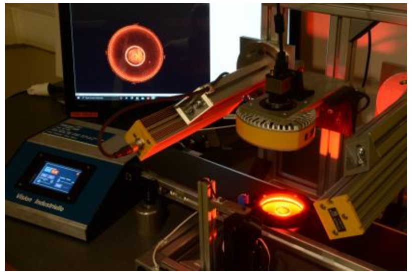
Barcode to decode

Area of sampling

https://barcode-coder.com/fr/specification-ean-13-102.html

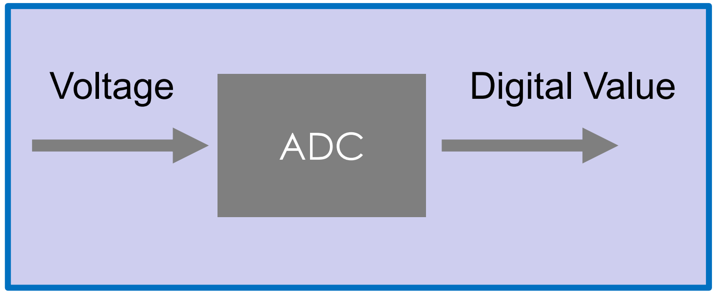
LEnsE 2024



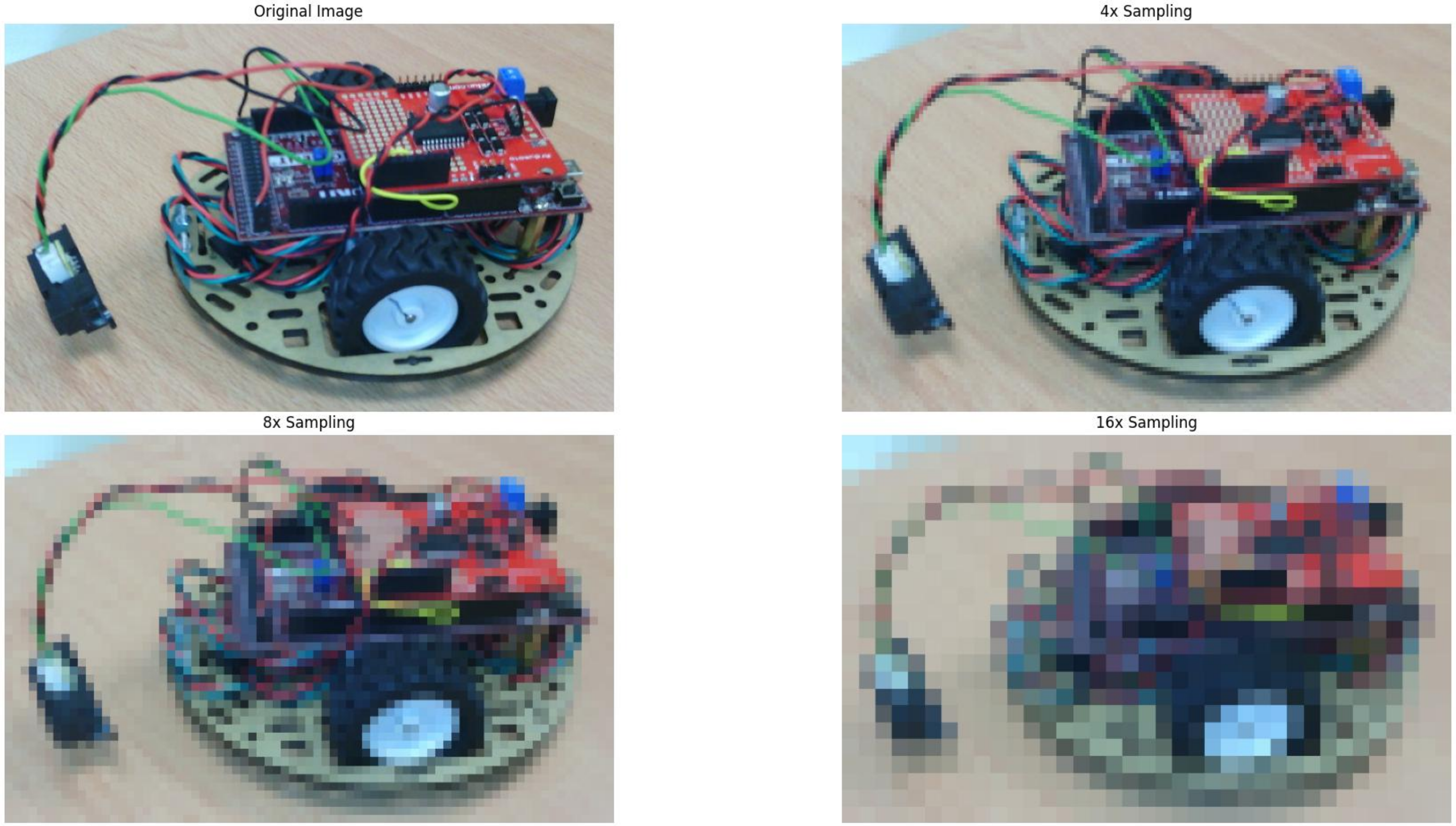


SC19 – Cameras and Interfaces

Sampling and quantization of an image



Sampling



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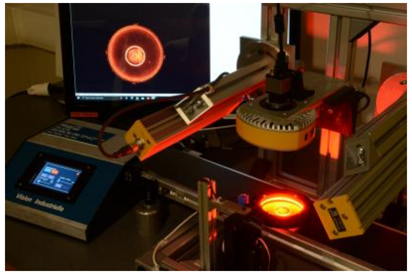
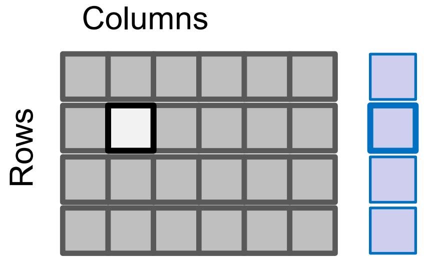


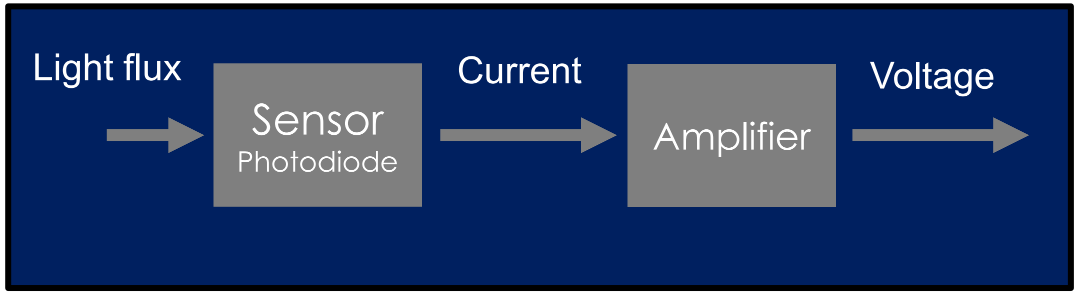
SC19 – Cameras and Interfaces

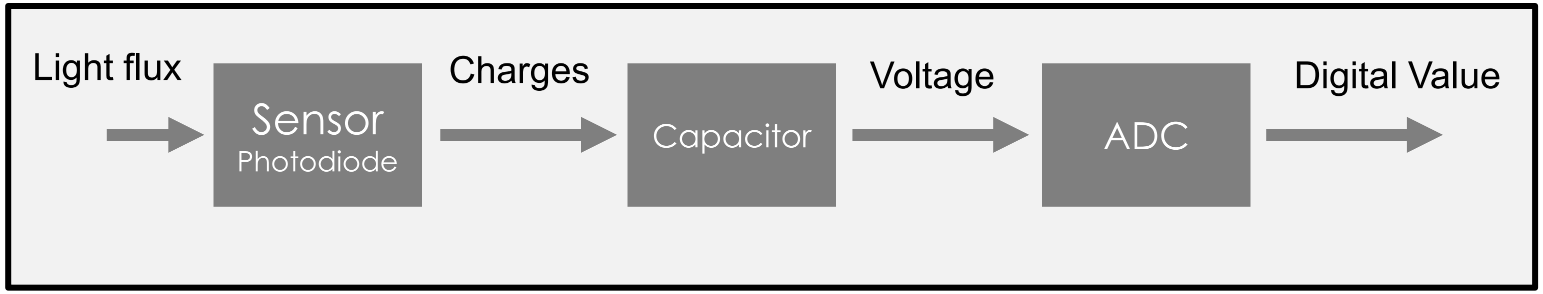
Camera / From analog to digital signal



Digital Camera

Device that transforms an array of **light flux sensors** into **digital data** called pixels





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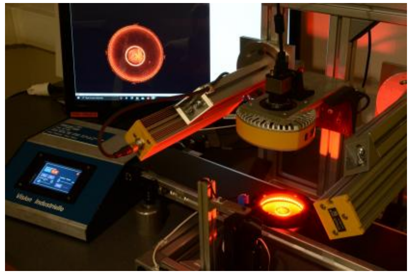
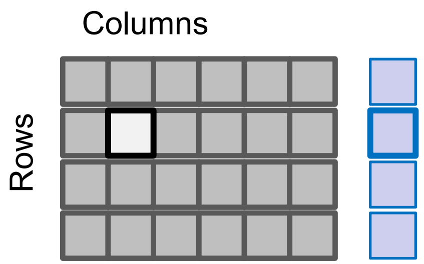
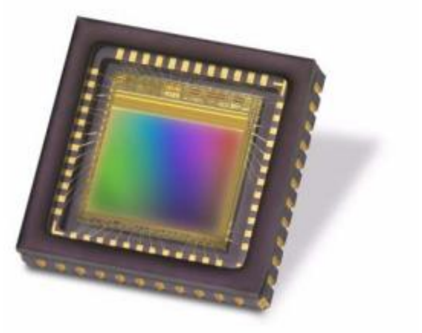


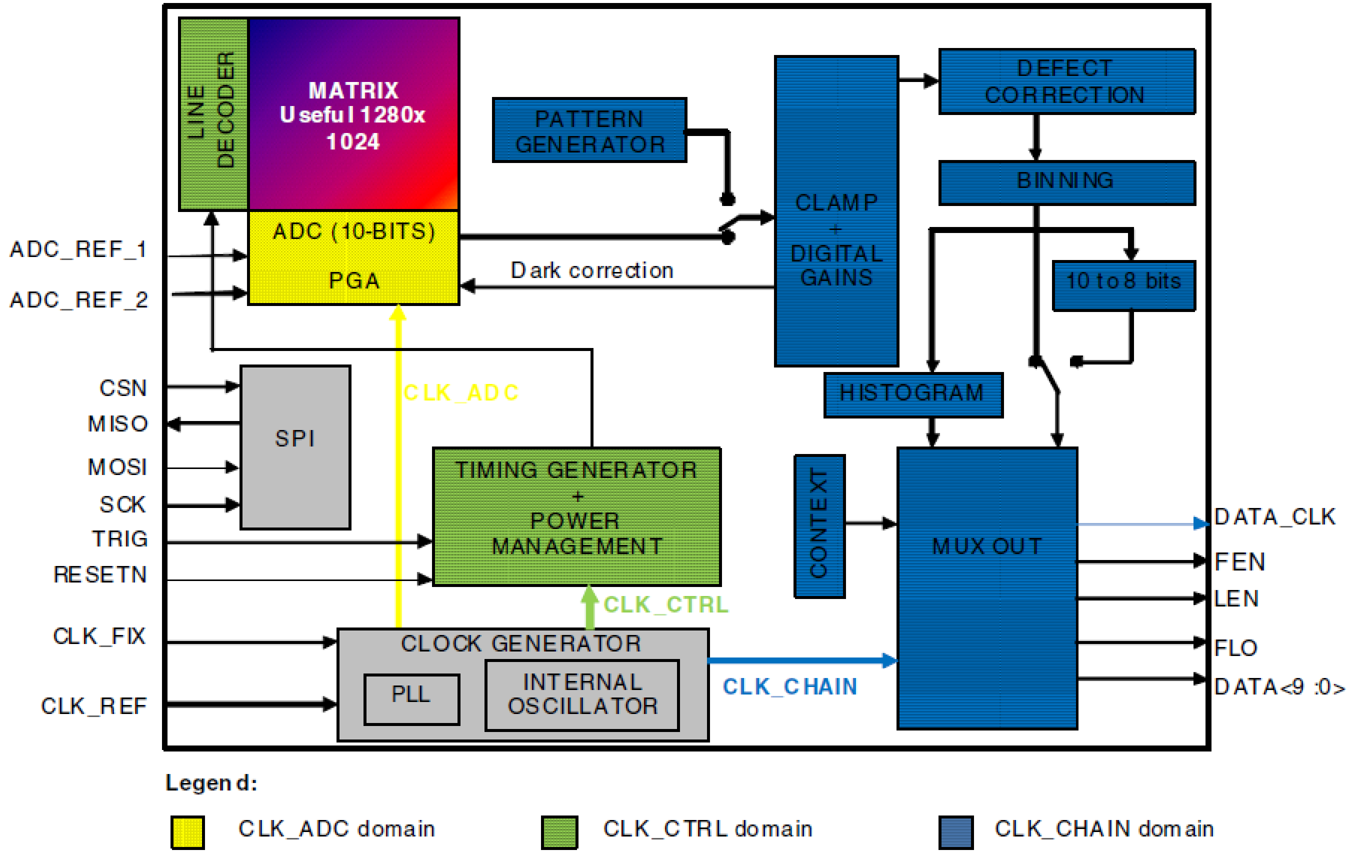
SC19 – Cameras and Interfaces

Inside a real sensor



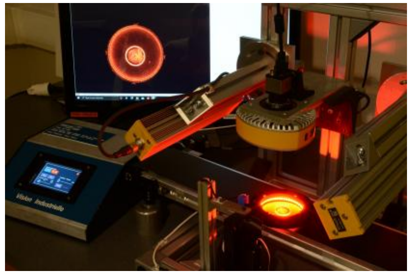


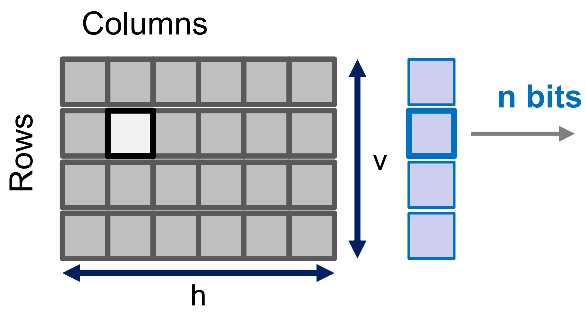
e2v sensor EV76C560ACT



SC19 – Cameras and Interfaces

Quantity of data per image





Nb of pixels = **h** x **v**

Nb of pixels = **1280** x **1024**

Each pixel is converted into **n bits**.

Each image has a total amount of binary data :

Nb of data (bits) = **Nb of pixels** x **n**

Nb of data (bits) = **1280** x **1024** x **10**
= **13 107 200** bits

Capteur EV76C560 Typical electro-optical performance @ 25°C and 65°C, nominal pixel clock

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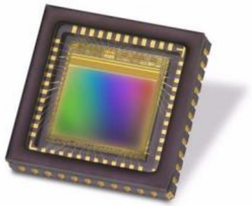
	SNR Max	dB	41	39
	MTF at Nyquist, λ=550 nm	%	50	
	Dark signal [1]	LSB_{10}/s	24	420
	DSNU[1]	LSB_{10}/s	6	116
	PRNU [2] (RMS)	%	<1	
	Responsivity [3]	$LSB_{10}/(Lux.s)$	6600	
Electrical interface	Power supplies	V	3.3 & 1.8	
	Power consumption: Functional [4] Standby	mW µW	< 200 mW 180	

1. Min gain, 10 bits.
2. Measured @ Vsat/2, min gain.
3. 3200K, window with AR coating, IR cutoff filter BG38 2 mm.
4. @ 60 fps, full format, with 10 pF on each output.



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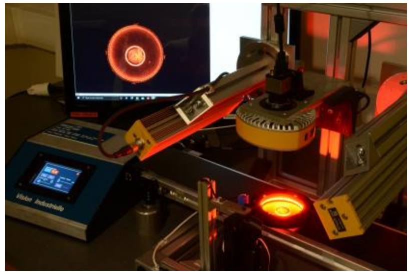


SC19 – Cameras and Interfaces

Frame Rate

Each image has a total amount of binary data :

Nb of data (bits) = **Nb of pixels** x **n**

The amount of data per second :

Nb of data per s (bits/s) = **Nb of data** (bits) x **FPS**

Frame rate

Number of individual frames captured **per second** by a device

Expressed in frames per second (fps)

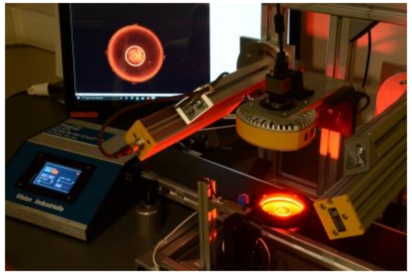
Higher framerates result in smoother motion in video footage

Example for a 4k camera in 12 bits @ 30 fps :

Nb of data (bits) = **3840** x **2160** x **12** = **99 532 800** bits

Nb of data per s (bits/s) = **99 532 800** x **30** = **2,9 billions of bits / s** = **2,78 Gbit/s**

In 2024, the transfer rate of a home router (optical fiber) is theoretically 8 Gbit/s (Free telecom - France)

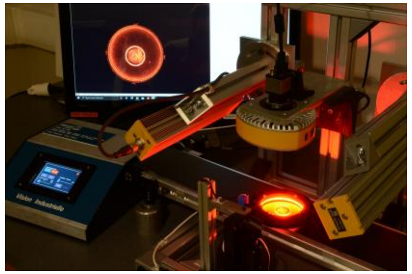


SC19 – Cameras and Interfaces

Interface for data transfer

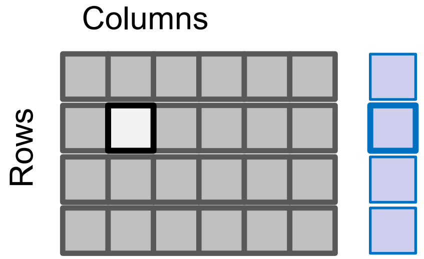
The data from a camera is transferred via **an interface**.
There are several types of standard interfaces.

	USB 3.0	10 GigE	CameraLink	Coaxpress
Bandwith	5 to 20 Gbit/s	1.2 Gbits/s	Base : 2 Gbits/s Full : 5.4 Gbits/s (2 cables)	12.5 Gbits/s per cable
Cable length	3 m	100 m	7 to 15 m	20 to 40 m
Power	4.5 to 25 W	30 W *	Optional	13 W / cable
Frame Grabber	Not Required	Not Required	Required	Required
GeniCam	Required	Required	Optional	Required



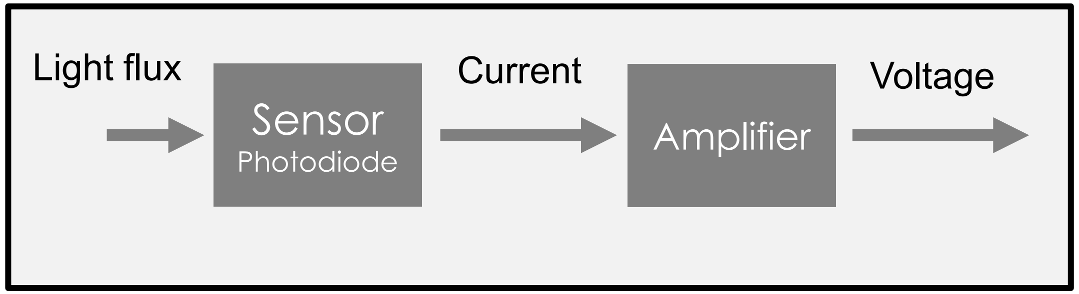
SC19 – Cameras and Interfaces

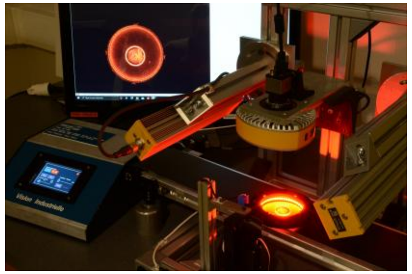
Dark Current



Dark Current

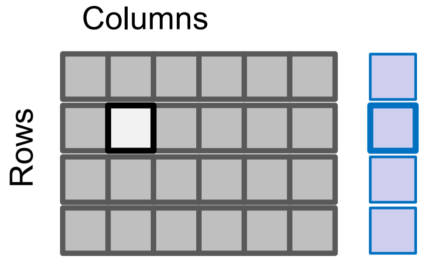
Response of the sensor to **complete darkness**





SC19 – Cameras and Interfaces

Black level : an offset to compensate electronic defaults

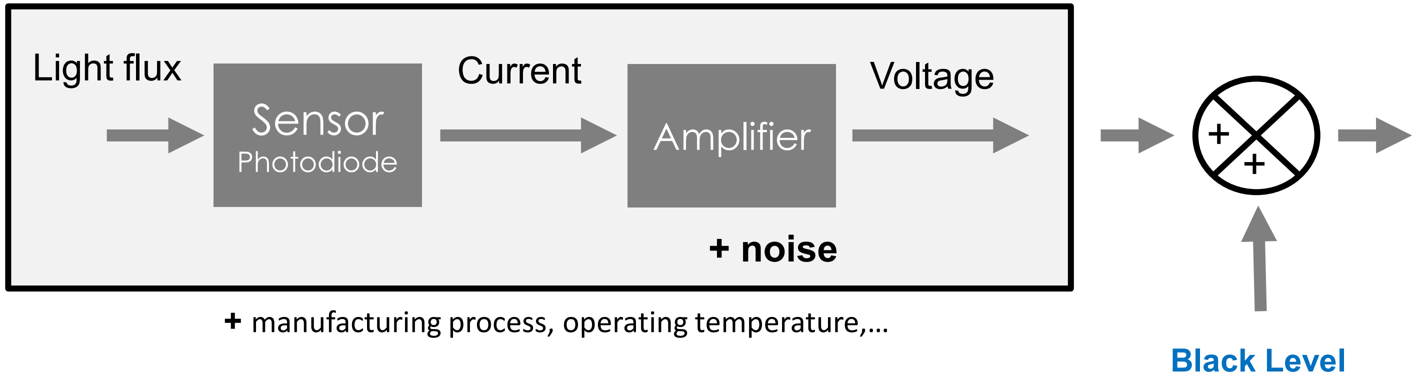


Dark Current

Response of the sensor to **complete darkness**

Black Level

Change the **overall brightness** of an image.

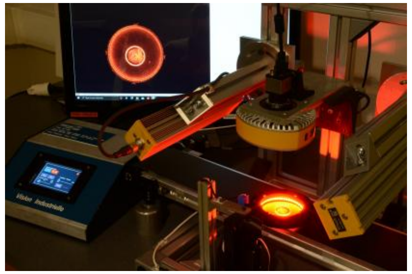


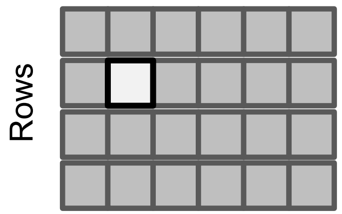
*Adjusting the camera's black level will result in **an offset to the pixel's gray values** output by the camera.*

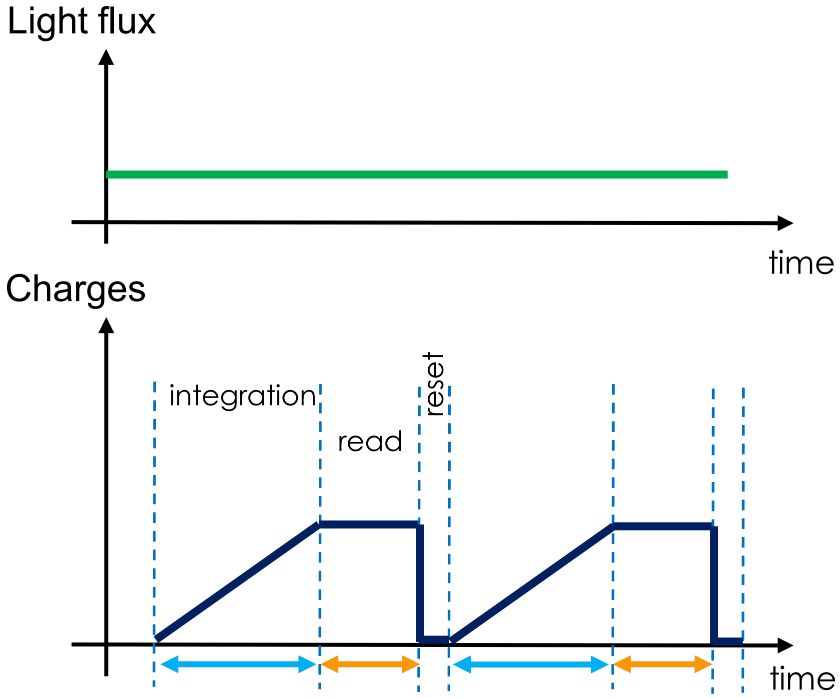
Due to ***various physical and electronic factors***, the sensor's output is never zero, even in the complete absence of light

SC19 – Cameras and Interfaces

Exposure Time





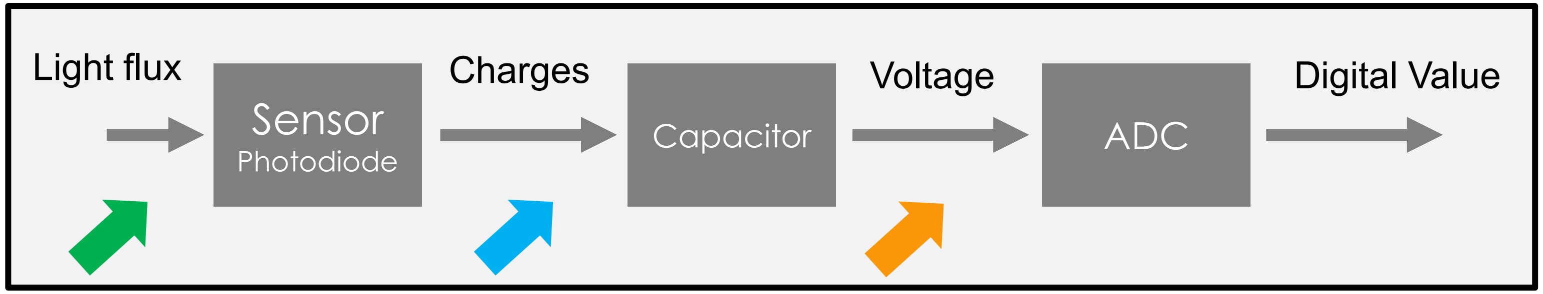


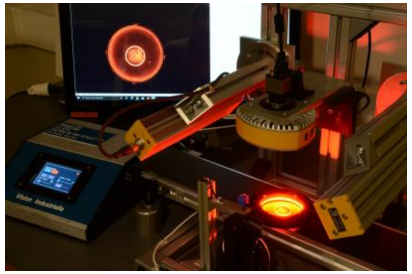
Exposure Time

Duration for which the **camera's sensor is exposed to light**, when capturing an image.

This parameter determines the amount of light collected.

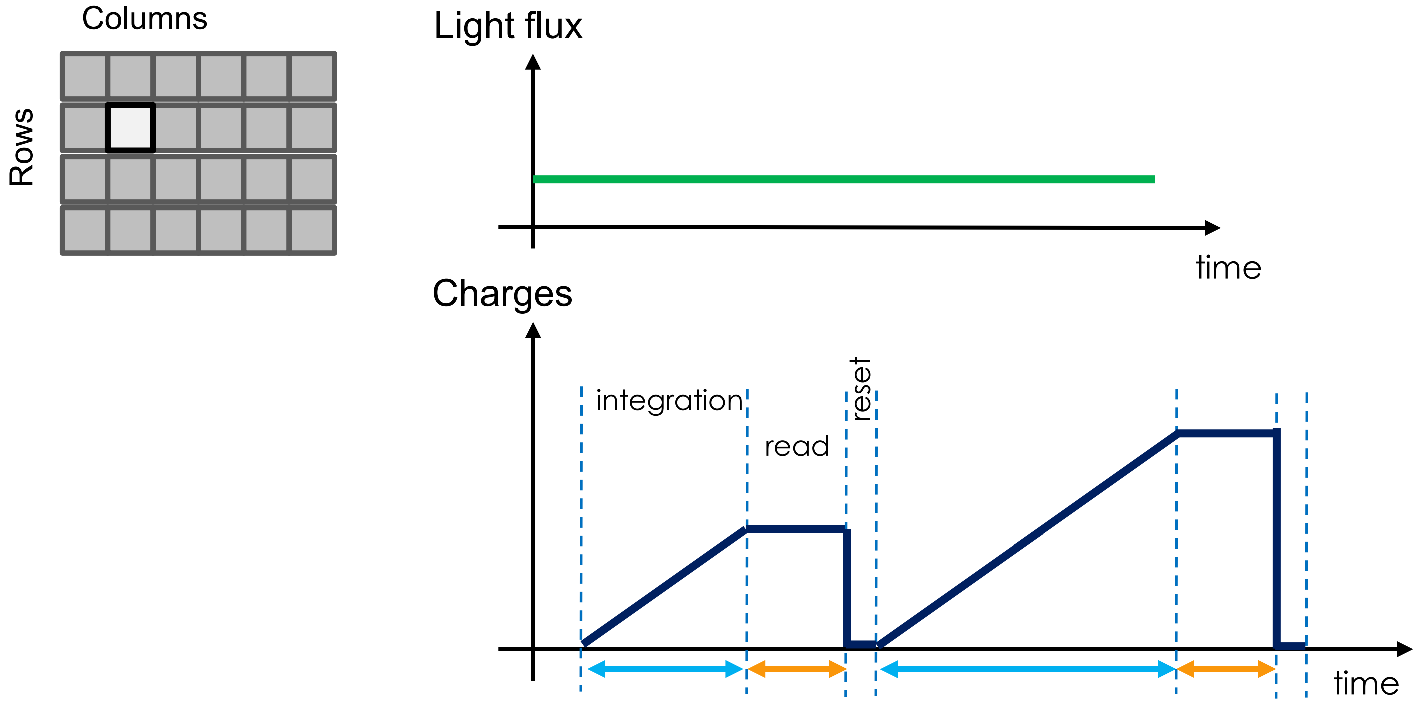
i.e. the amount of collected charges coming from the sensor stored in a capacitor





SC19 – Cameras and Interfaces

Exposure Time



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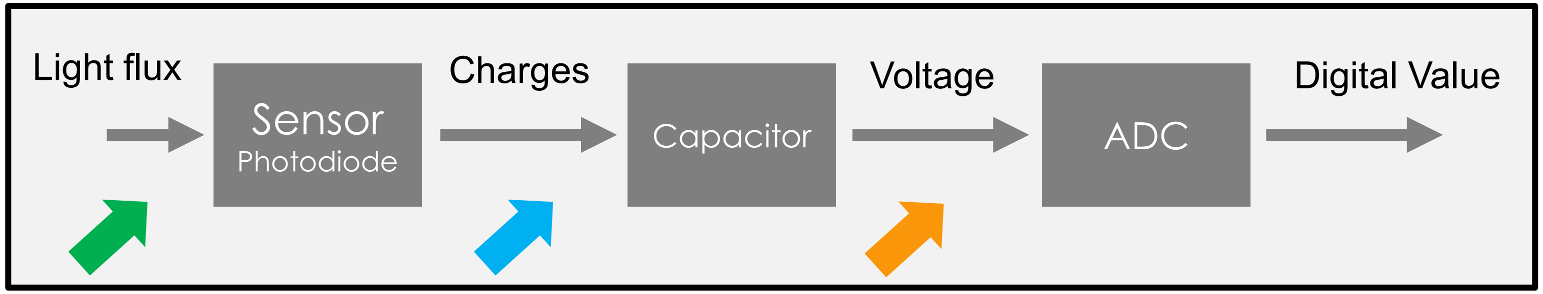
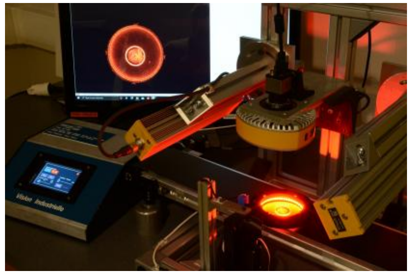
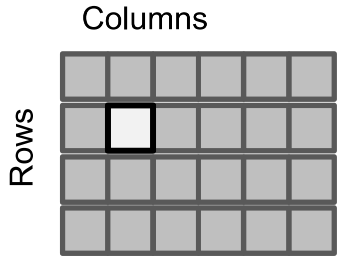
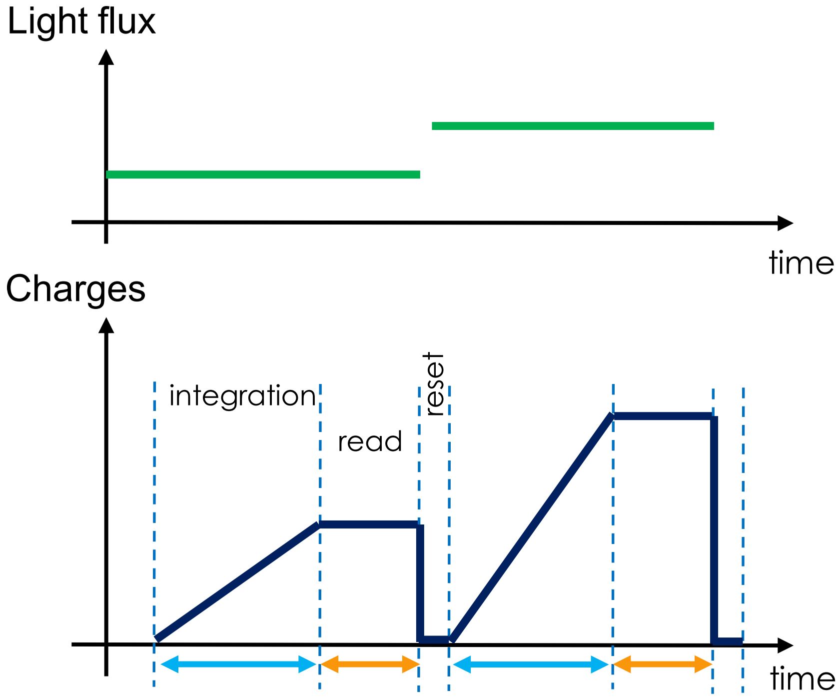




SC19 – Cameras and Interfaces

Exposure Time



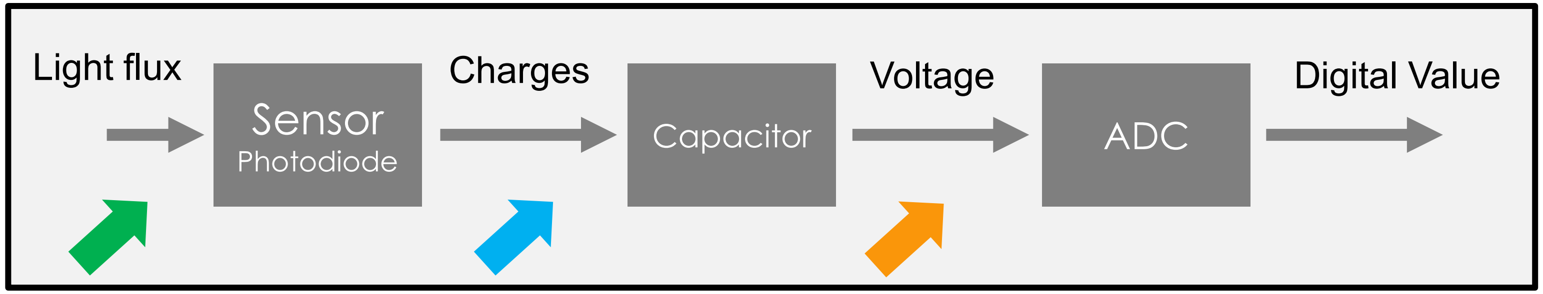


Exposure Time

Duration for which the **camera's sensor is exposed to light**, when capturing an image.

This parameter determines the amount of light collected.

i.e. the amount of collected charges coming from the sensor stored in a capacitor



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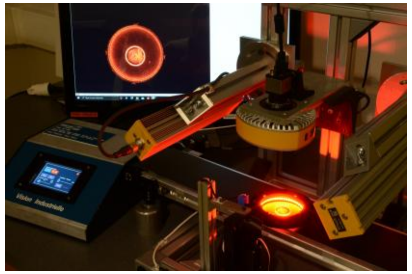
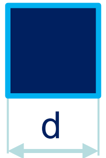
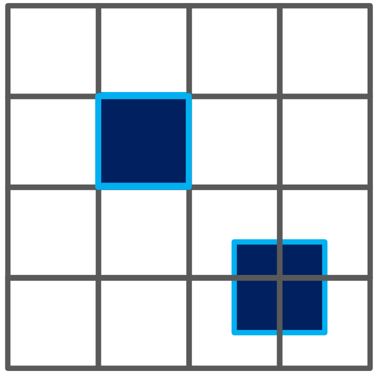


SC19 – Cameras and Interfaces

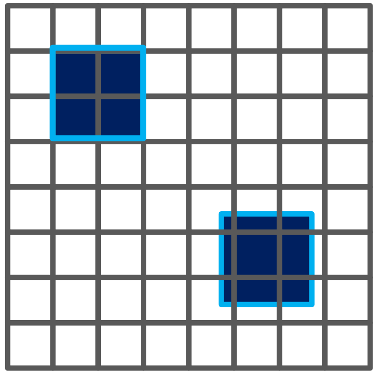
Spatial Resolution



Small object to detect



$$P = d$$



Security factor S

$$P = \frac{d}{S}$$

Spatial resolution / P

Distance observed by a single pixel in a given direction

This security factor is due to the Nyquist-Shanon theorem.

And S >= 2

*To verify is the spatial resolution is good enough, **calibration target** can be used. (Foucault)*

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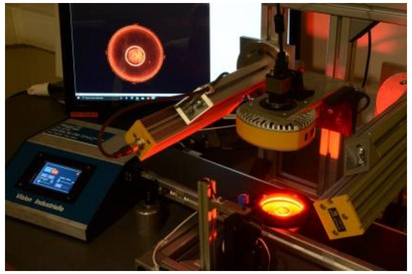
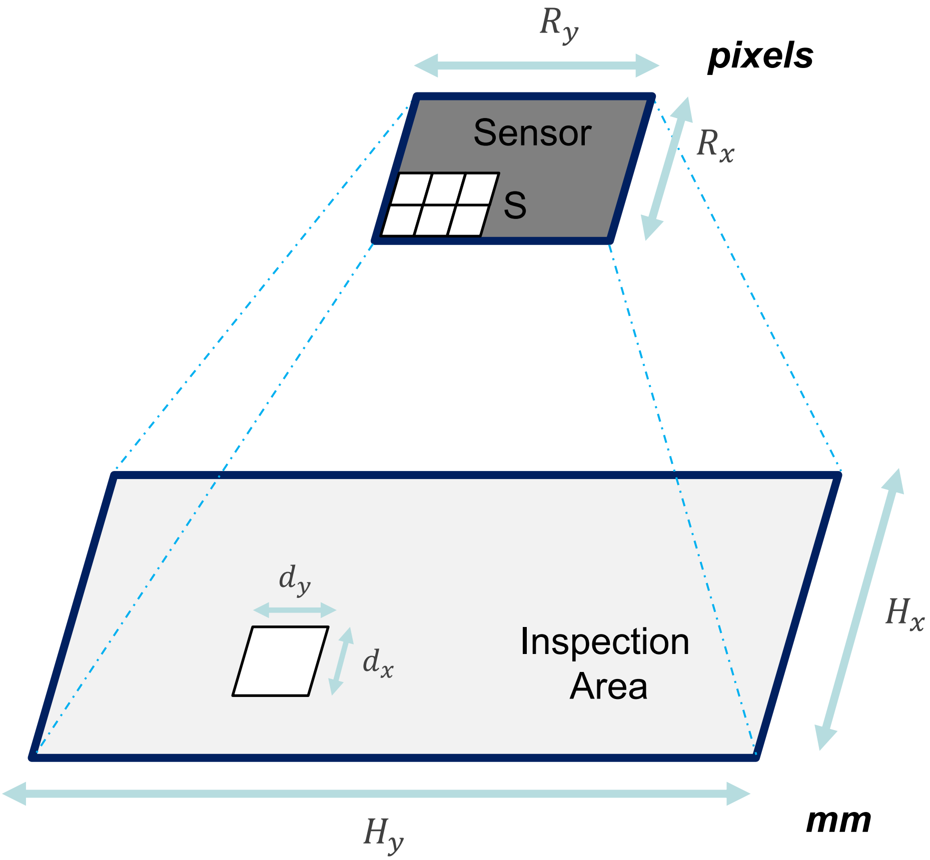


SC19 – Cameras and Interfaces

Resolution of the sensor



Spatial resolution / P

Distance observed by a single pixel in a given direction

$$\boxed{P = \frac{d}{S}}$$

Sensor resolution (pixels)

$$\boxed{R = \frac{H}{P} = \frac{S \times H}{d}}$$

H (mm) → R (px)
d (mm) → S (px)
P (mm) → 1 (px)

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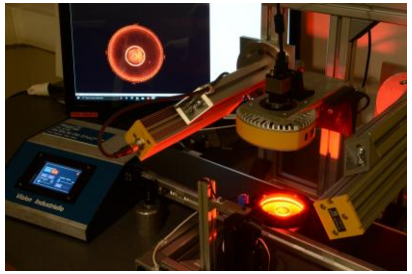
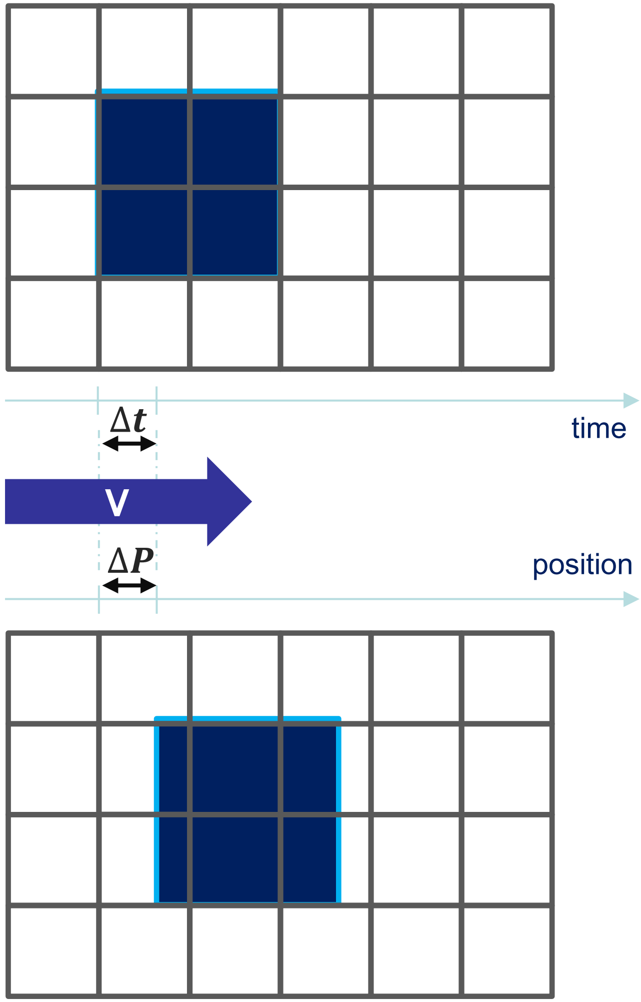


SC19 – Cameras and Interfaces

Motion, sharp image and maximum exposure time



V : motion speed (mm/s)

Motion blur perception threshold
to obtain a sharp image
is between

1/2 and 1/5 of a pixel

Spatial resolution / P

Distance observed by a single pixel in a given direction

$$\boxed{P = \frac{d}{S}}$$

Displacement

$\boldsymbol{P} \times \Delta\boldsymbol{P}$ (mm) → $\Delta\boldsymbol{t}$ (s)

Time

$$\boxed{\Delta \boldsymbol{t} = \frac{\boldsymbol{P} \times \Delta \boldsymbol{P}}{\boldsymbol{V}}}$$