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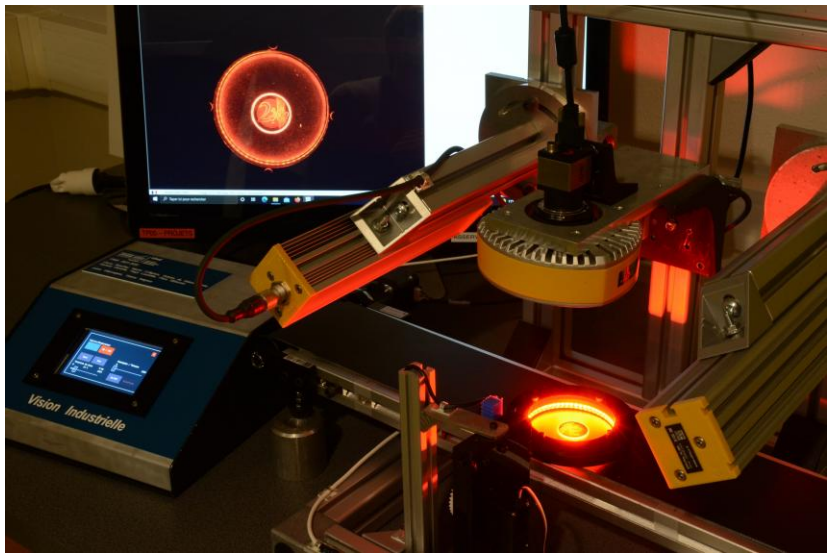
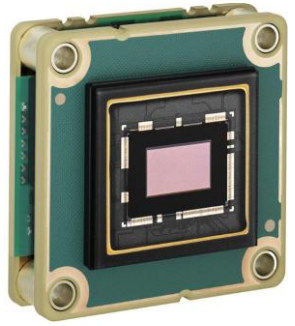
SC 19 – Machine Vision

Cameras and Interfaces

Julien VILLEMEJANE



IDS Sensor



Basler Sensor / Mouser

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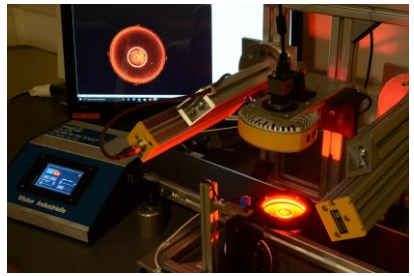

SC19 – Cameras and Interfaces

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

Characterize a camera and choose the interface

Sensor technology (2D, linear…)

CMOS Sensor characterization
(linearity, spatial homogeneity, noise…)

Protocols (Genicam, USB…)

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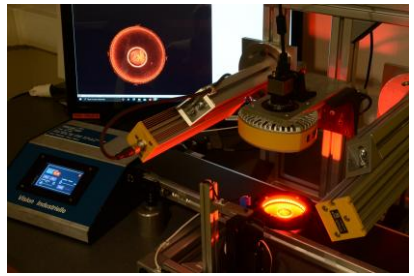
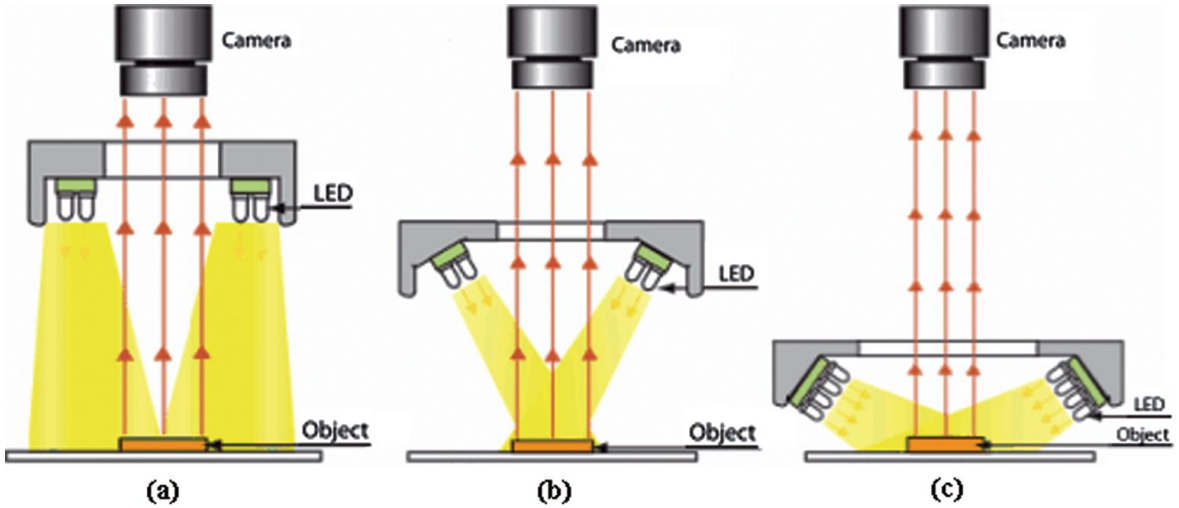


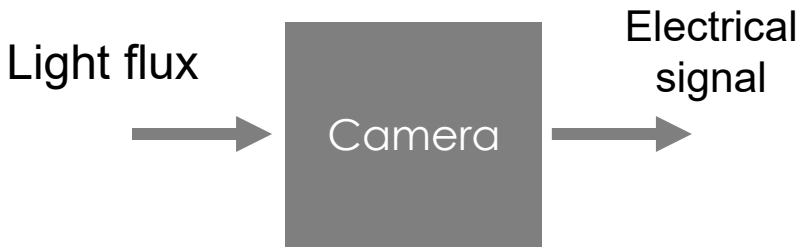
SC19 – Cameras and Interfaces

Camera in a machine vision chain



Camera

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



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.

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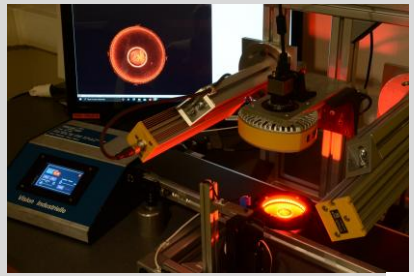
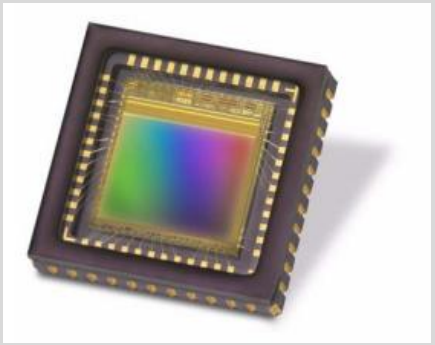


SC19 – Cameras and Interfaces

Anatomy of an IDS sensor

IDS UI-1240SE-C-HQ



e2v sensor EV76C560ACT

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

- Interface

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	

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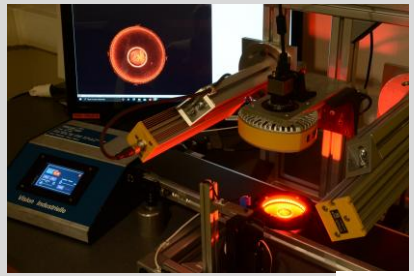
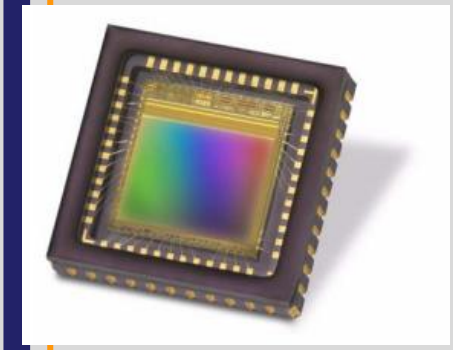


SC19 – Cameras and Interfaces

Main charateristics of the sensor



e2v sensor EV76C560ACT

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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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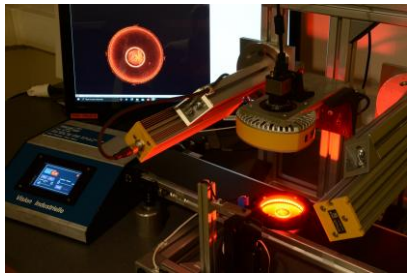
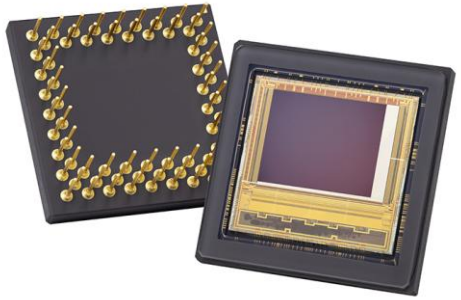


SC19 – Cameras and Interfaces

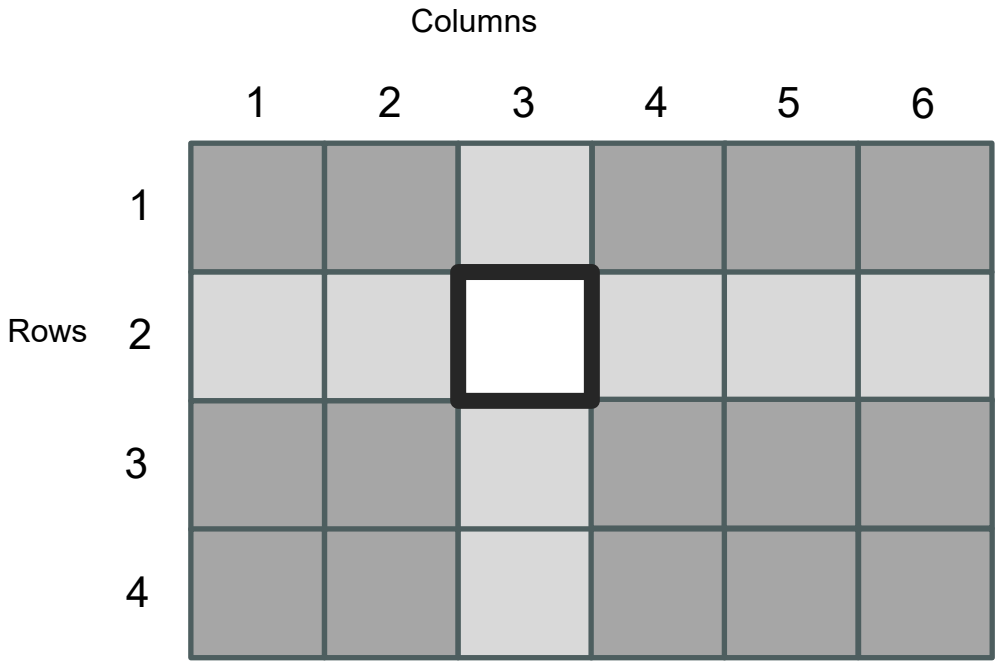
Camera / Array of small sensors

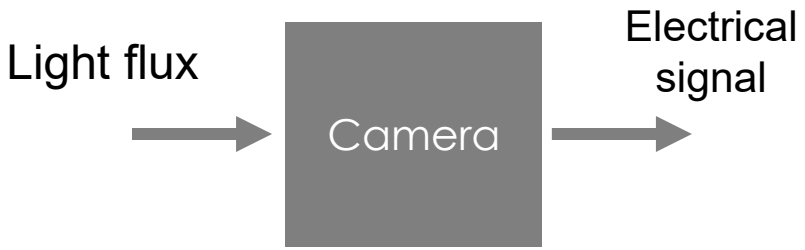


https://imaging.teledyne-e2v.com/products/2d-cmos-image-sensors/onyxmax/

Camera

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





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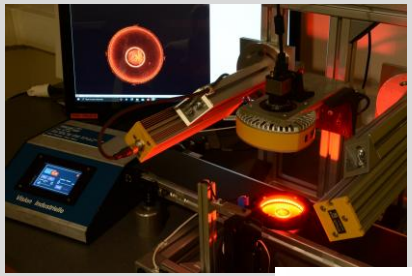
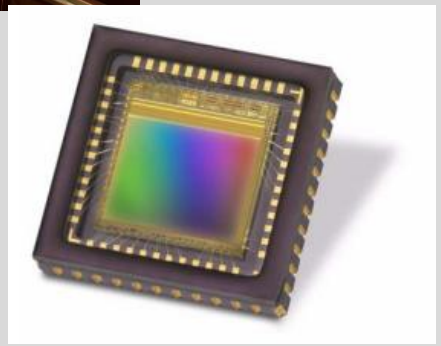


SC19 – Cameras and Interfaces

Camera / Array of small sensors



e2v sensor EV76C560ACT

Capteur	
Type de capteur	CMOS Couleur
Mode d'obturateur	Global / Rolling / Global Start
Caractéristique du capteur	Linéaire
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CAN	10 bit
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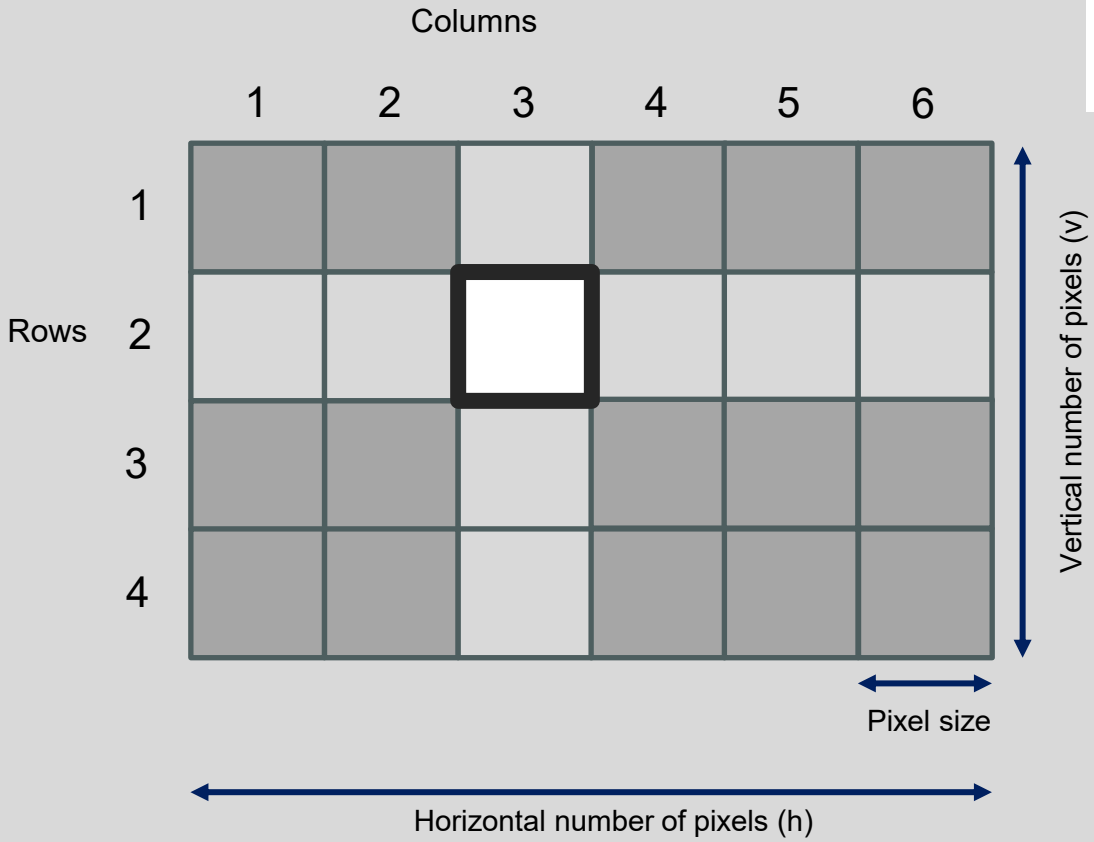
Diagonale du capteur optique	8,69 mm (1/1,84")
Taille de pixel	5,3 µm
Fabricant	e2v
Désignation du capteur	EV76C560ACT
Amplification (complet/RVB)	4x/4x



Resolution
Size / Form factor

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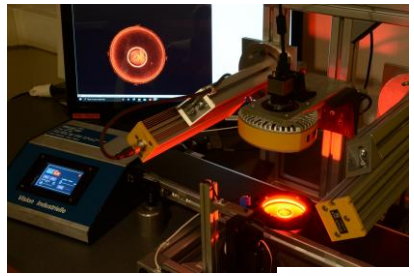
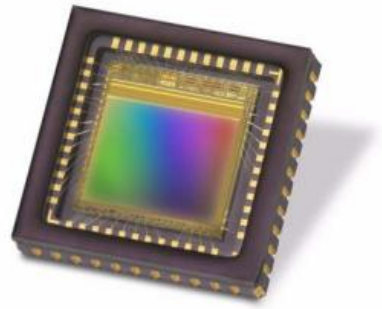
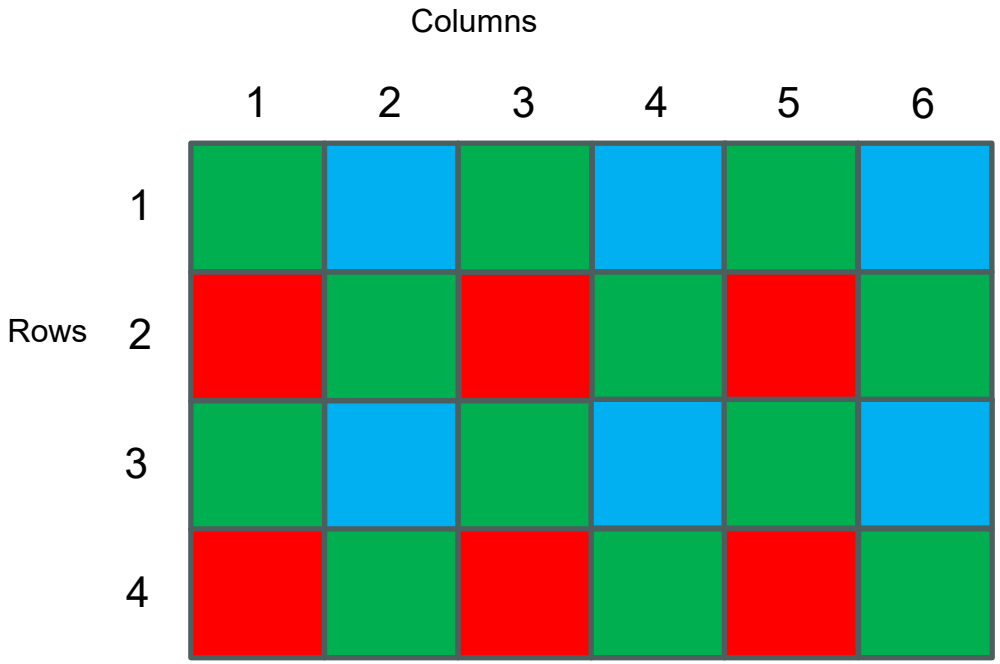


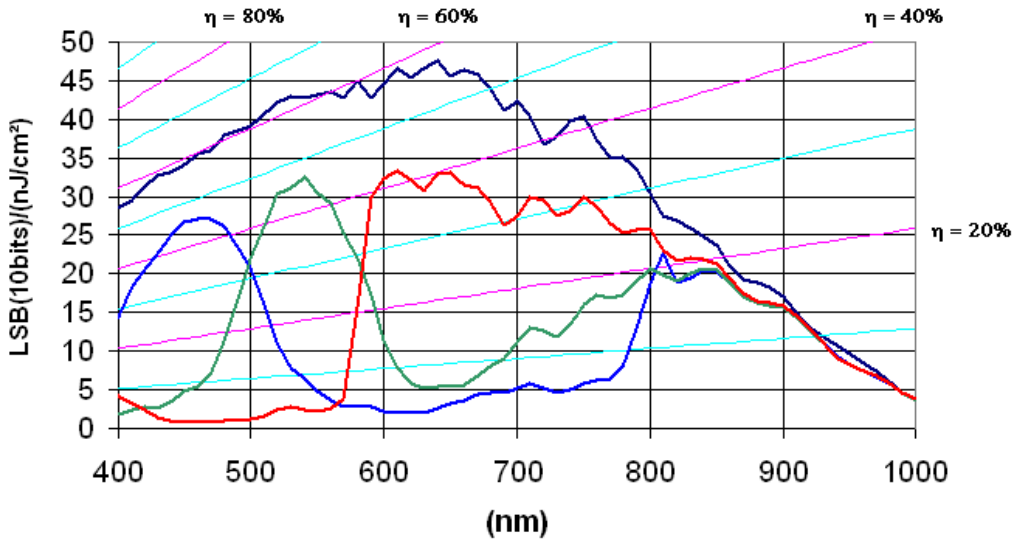
SC19 – Cameras and Interfaces

Camera / Bayer filter for color sensors



e2v sensor EV76C560ACT





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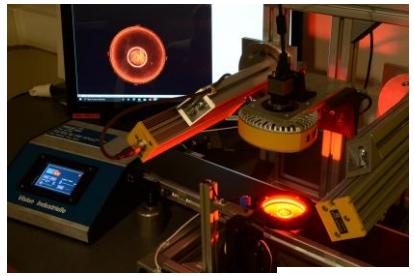
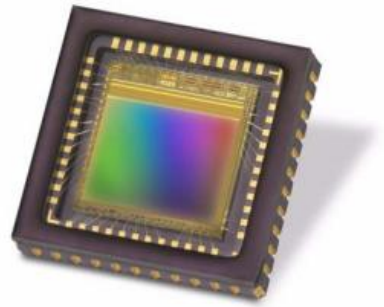
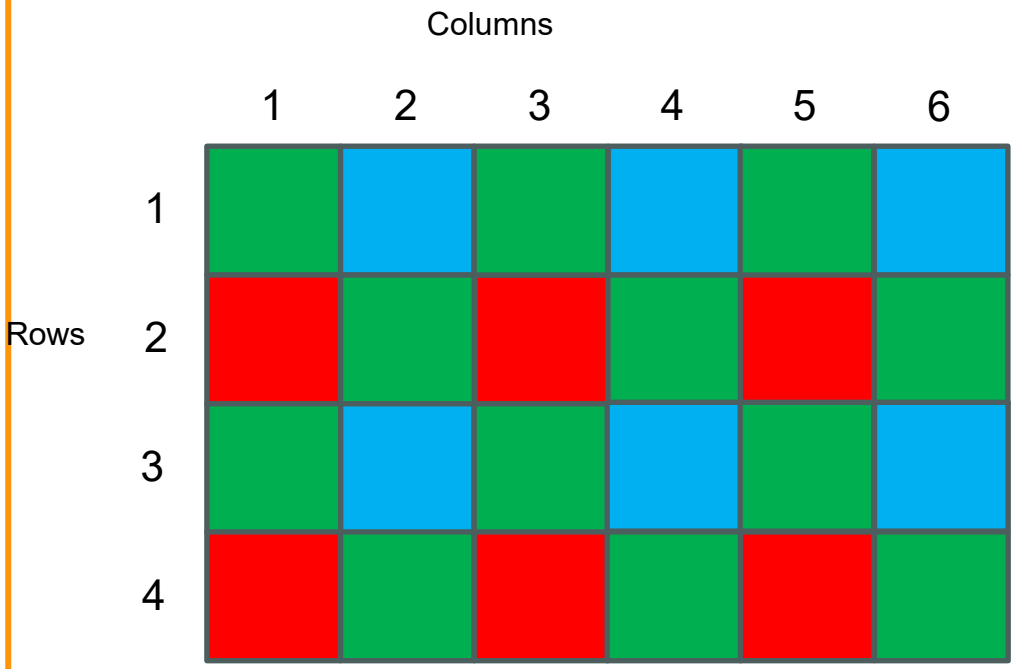


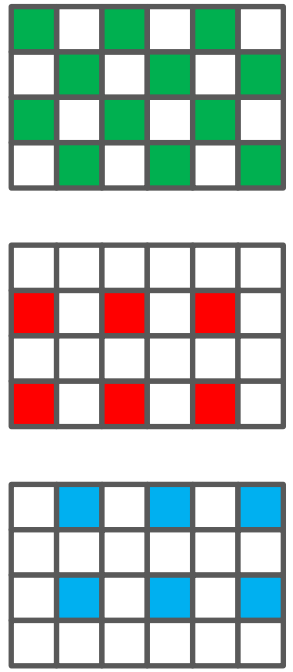
SC19 – Cameras and Interfaces

Camera / Bayer filter for color sensors



e2v sensor EV76C560ACT





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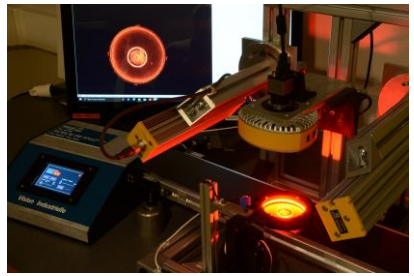
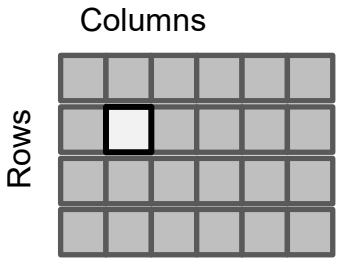


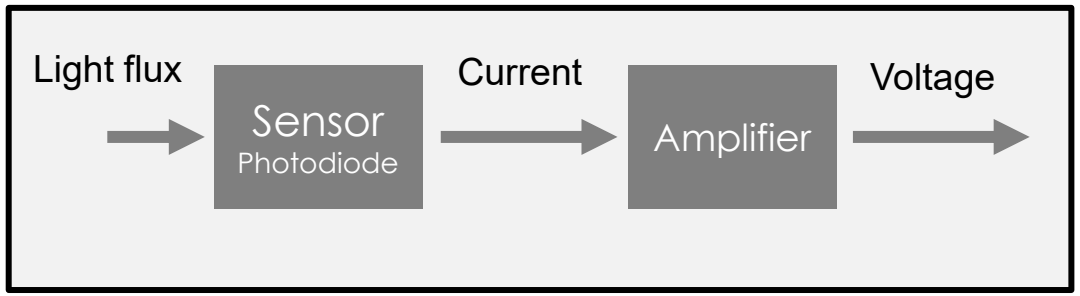
SC19 – Cameras and Interfaces

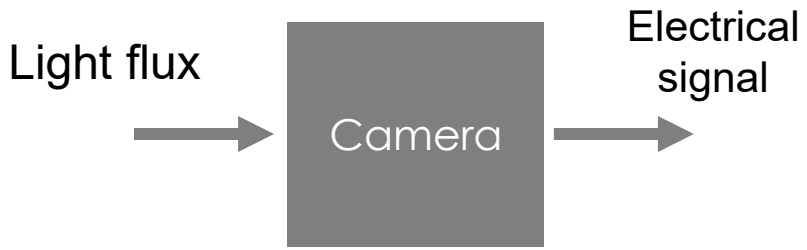
Camera / Inside a pixel

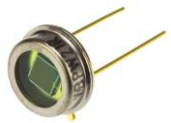


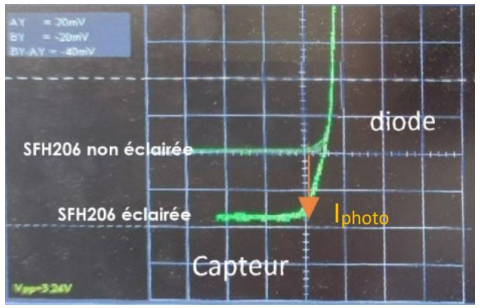
Camera

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









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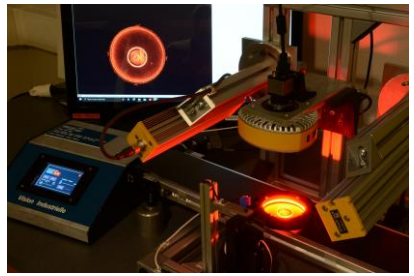
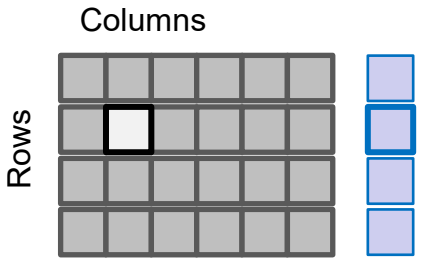


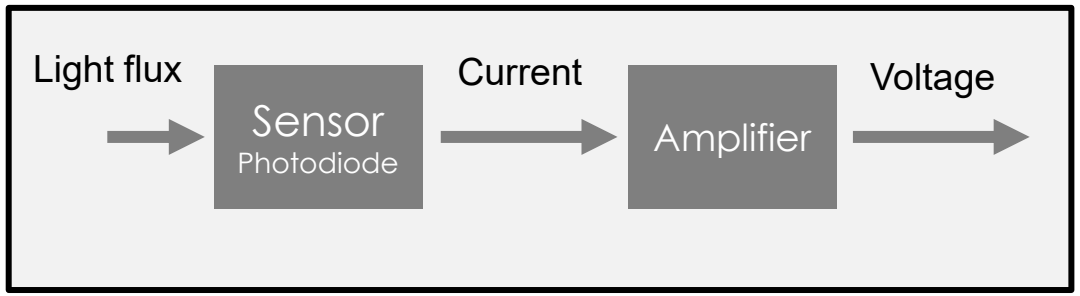
SC19 – Cameras and Interfaces

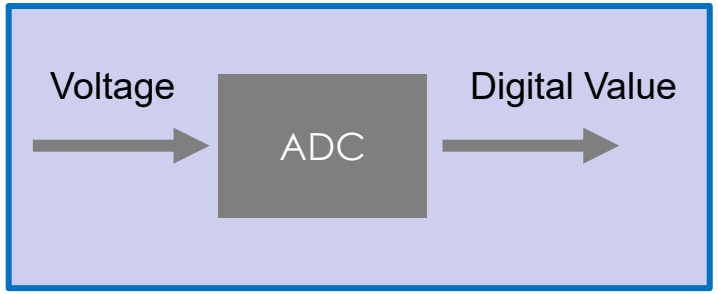
Camera / From analog to digital signal



Digital Camera

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





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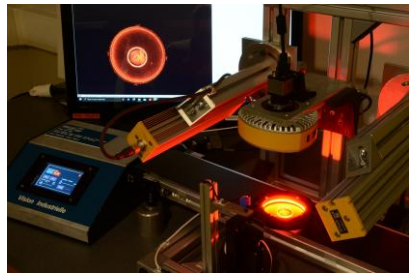
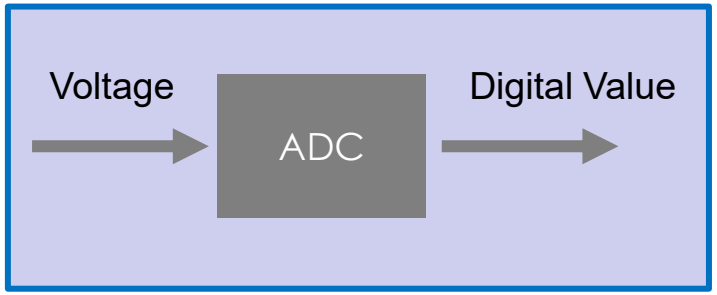
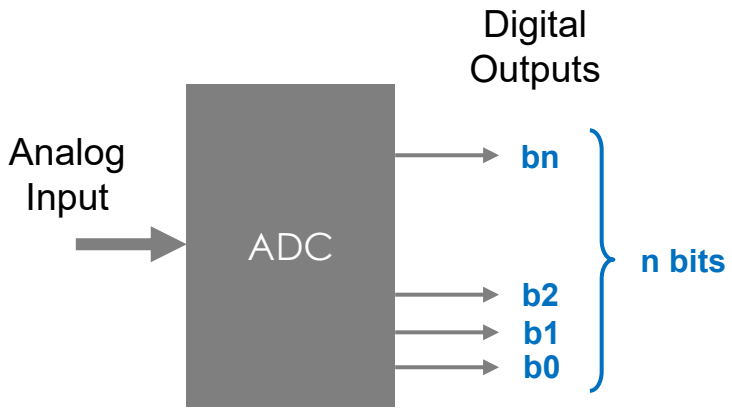


SC19 – Cameras and Interfaces

How an Analog to Digital Converter works ?



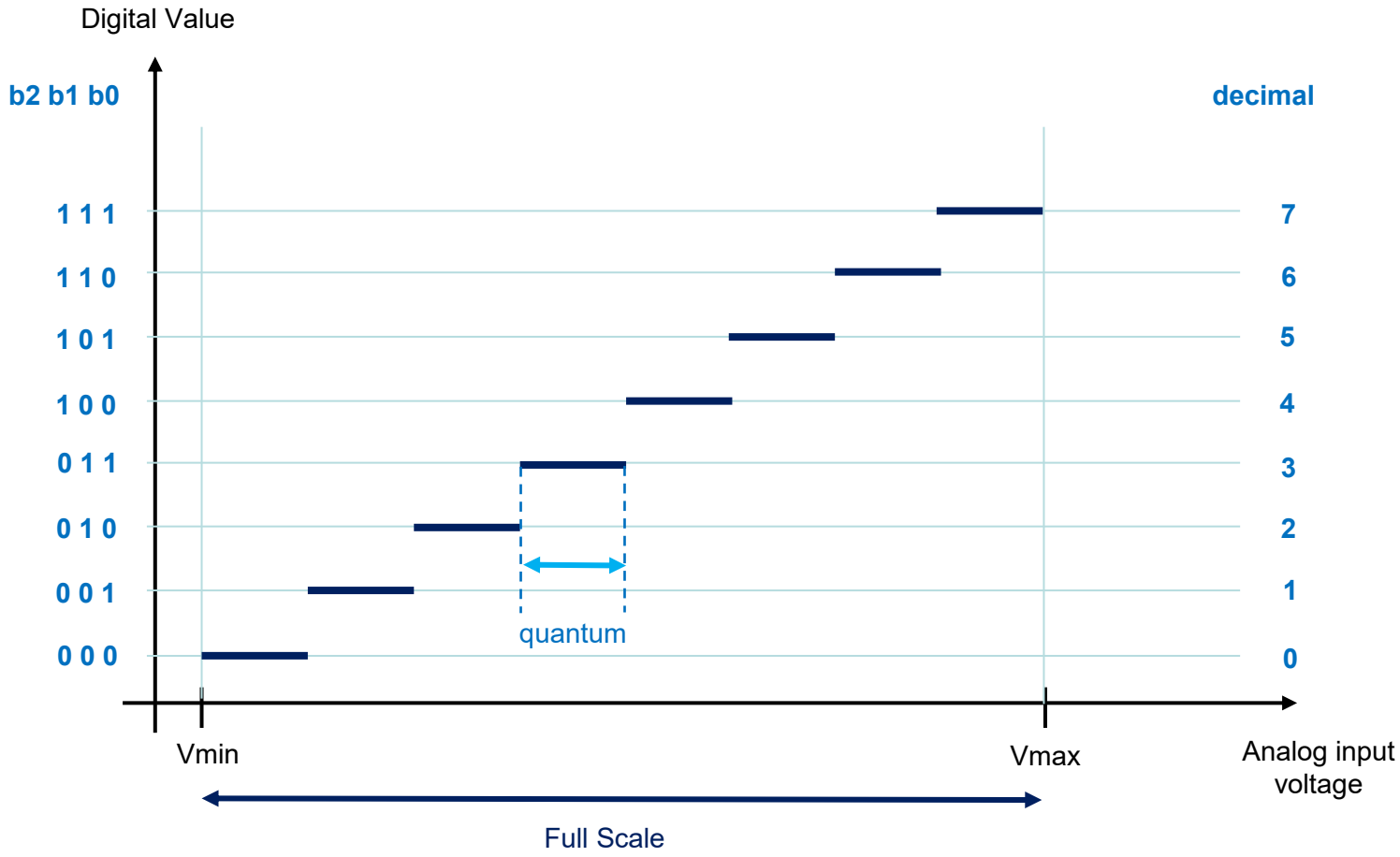


Each bit can have one of two values: **0** or **1**.

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

Example for n = 3 bits

Quantization



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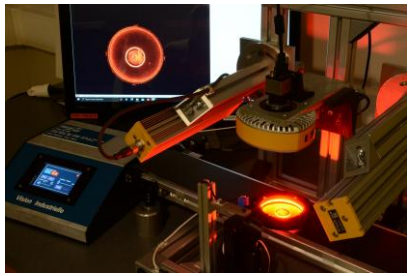
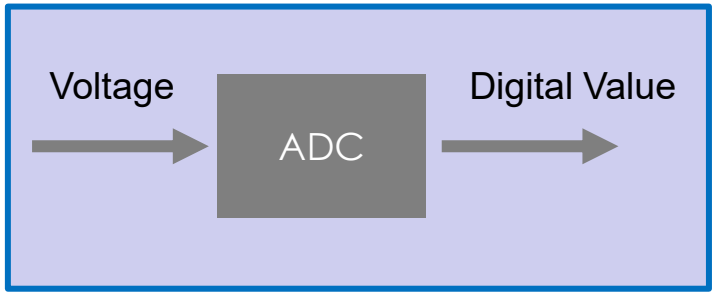
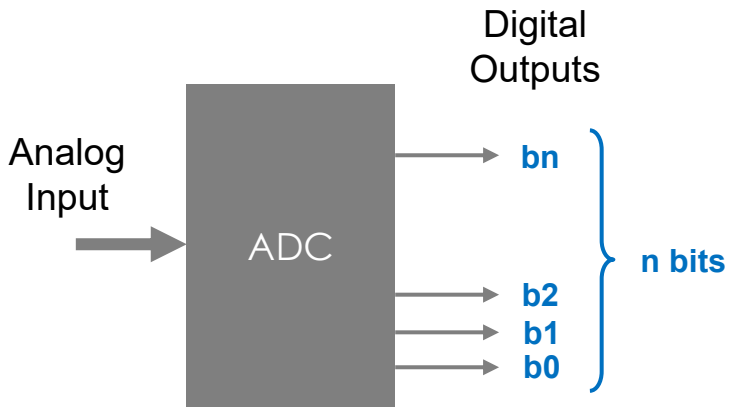


SC19 – Cameras and Interfaces

Sampling and quantization of an image





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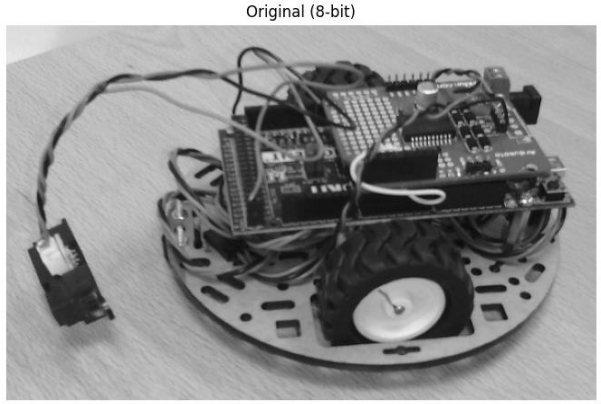

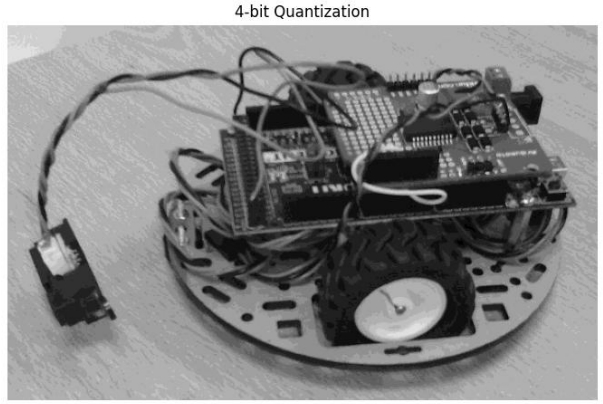

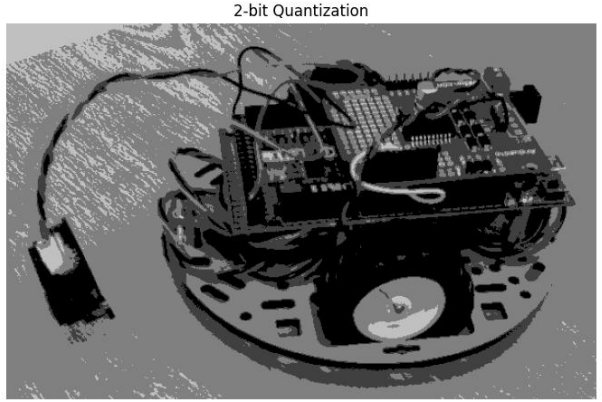

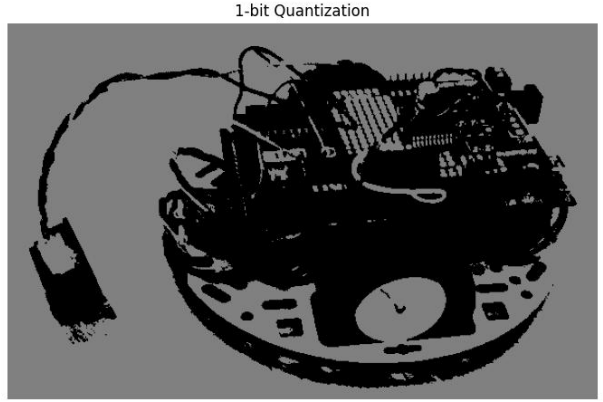

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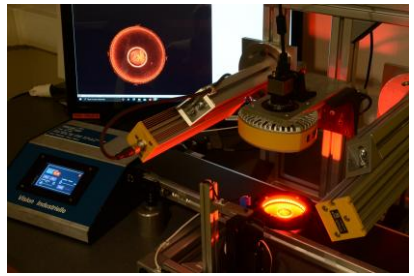
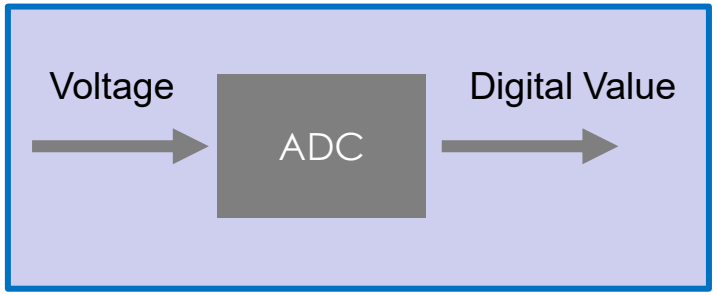


SC19 – Cameras and Interfaces

Sampling and quantization of an image

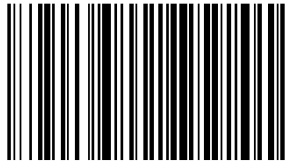


Sampling

Barcode to decode

Area of sampling

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

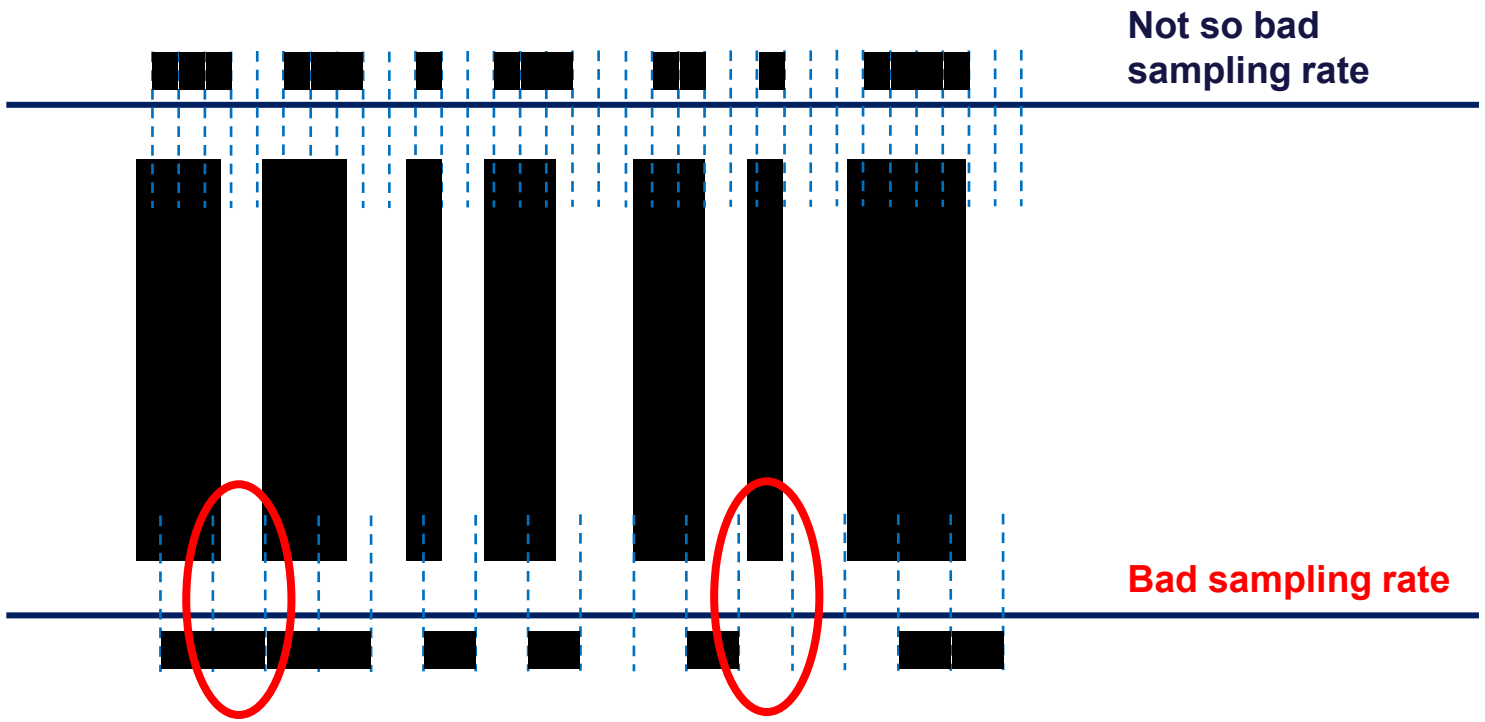


Sampling theorem

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.*



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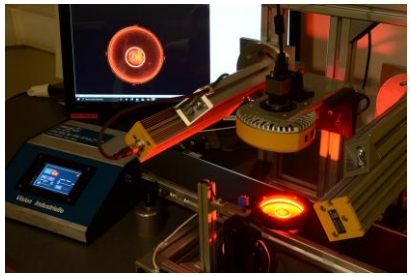
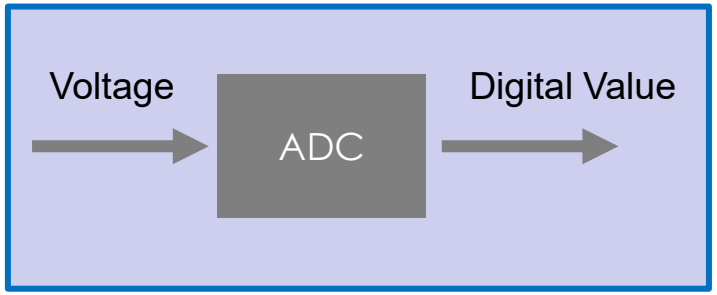
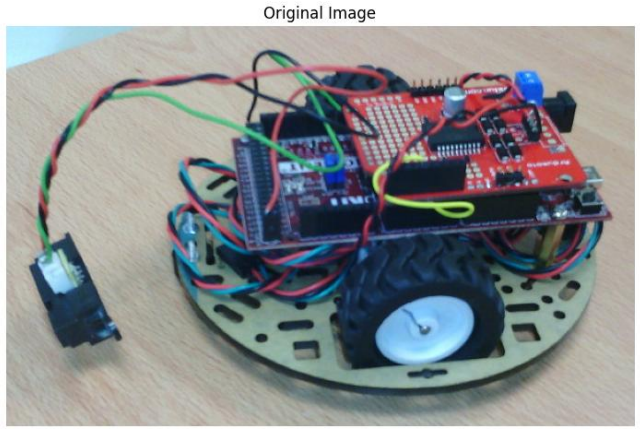


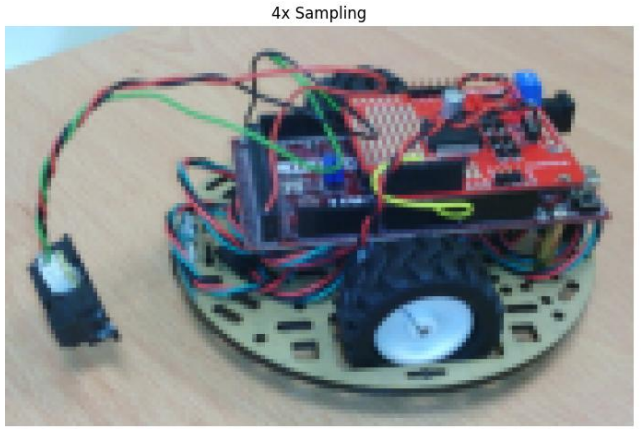
SC19 – Cameras and Interfaces

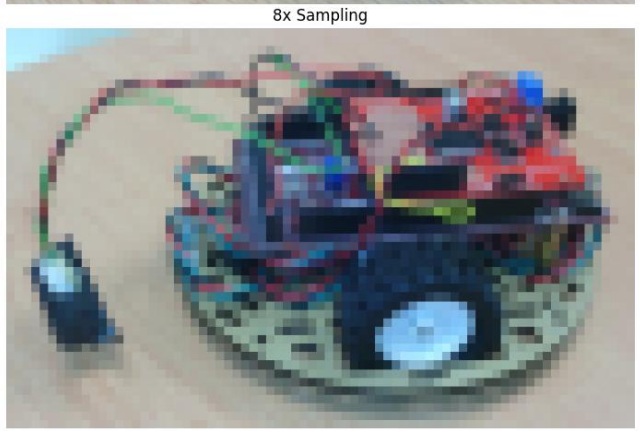
Sampling and quantization of an image



Sampling







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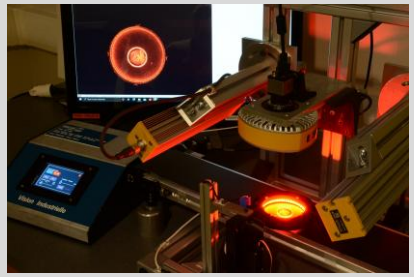


SC19 – Cameras and Interfaces

Camera / Array of small sensors

The **number of different values** that can be represented by **10 bits** is 2^{10} **= 1024**

In a ***Grayscale mode*** *:*

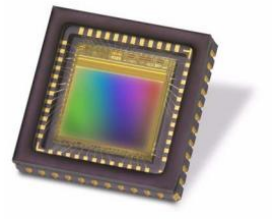
- a **black pixel** is represented by **0**
- a **white pixel** is represented by **1023**

Full scale of the ADC is **12 ke-**

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	

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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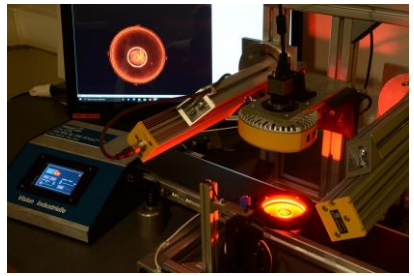
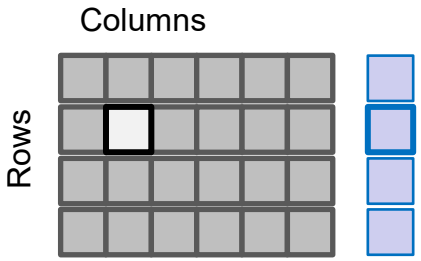
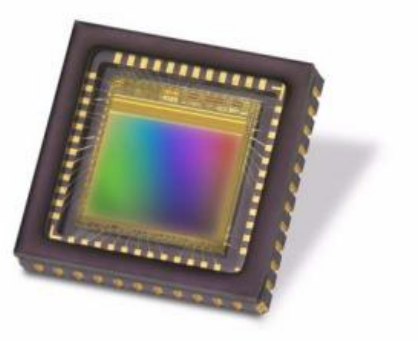


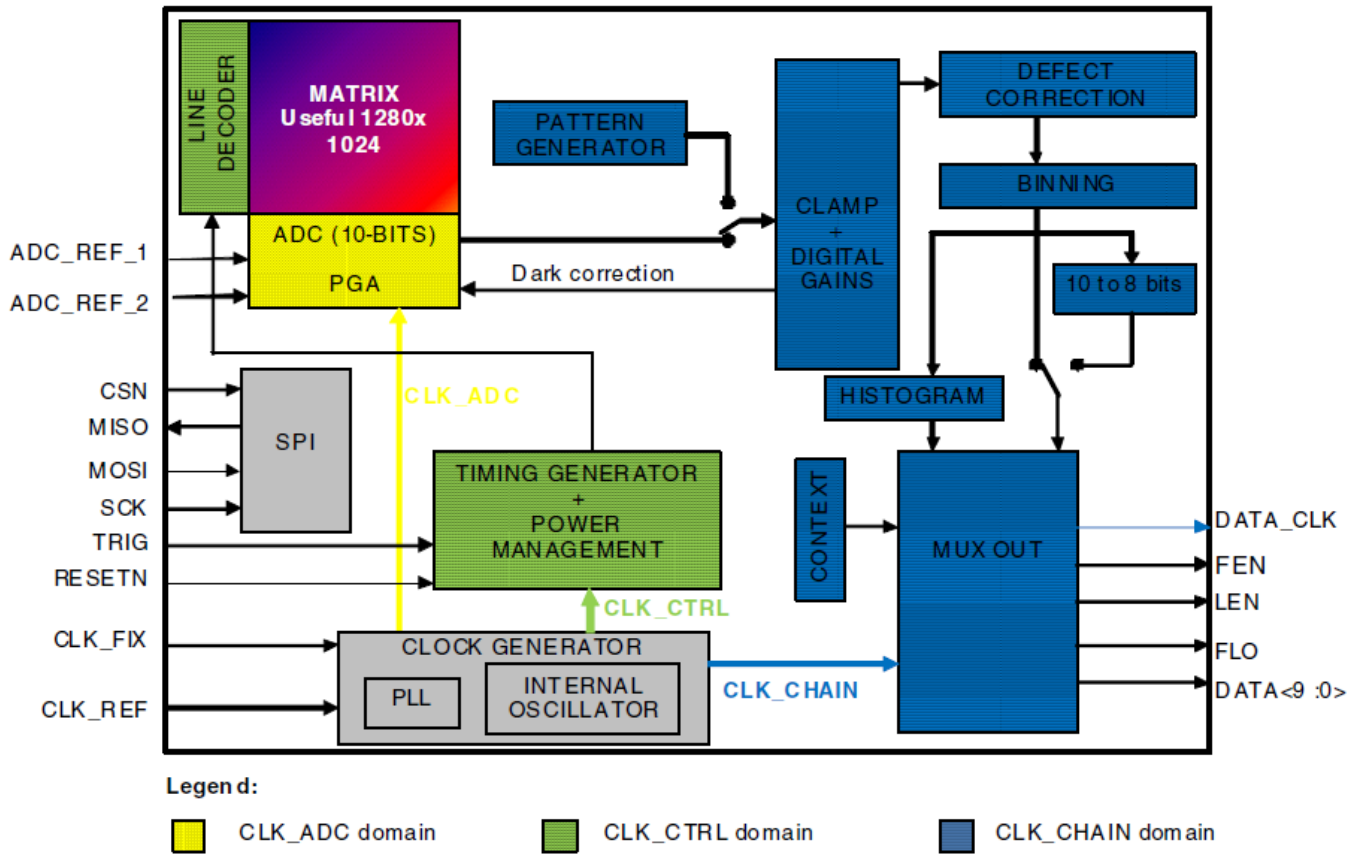
SC19 – Cameras and Interfaces

Inside a real sensor





e2v sensor EV76C560ACT



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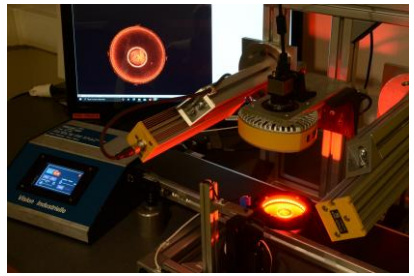
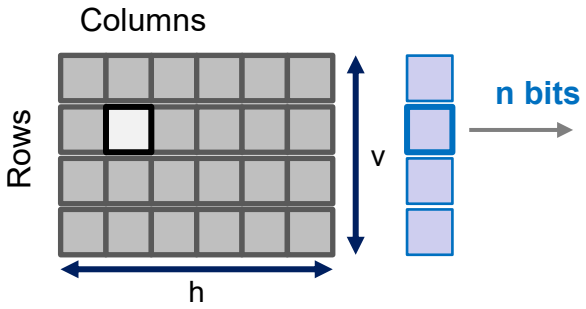


SC19 – Cameras and Interfaces

Quantity of data per image



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

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**

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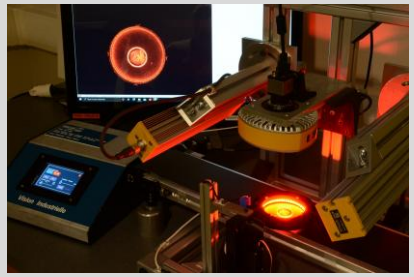
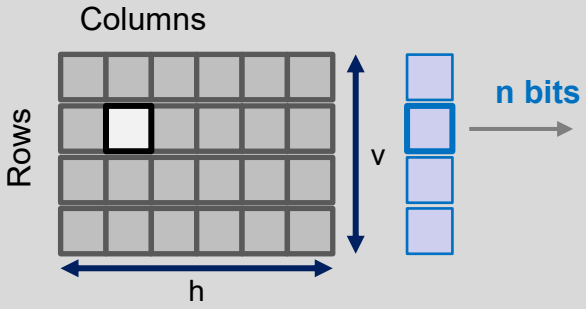


SC19 – Cameras and Interfaces

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 :

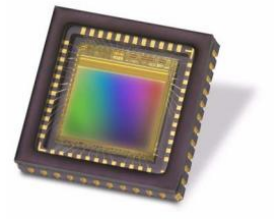
Nb of data (bits) = **Nb of pixels** x **n**

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

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	

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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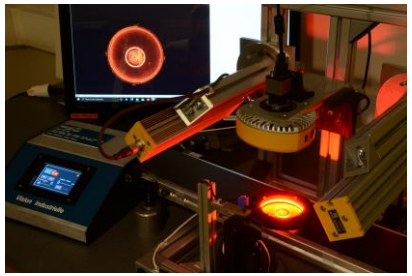

SC19 – Cameras and Interfaces

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**

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)

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

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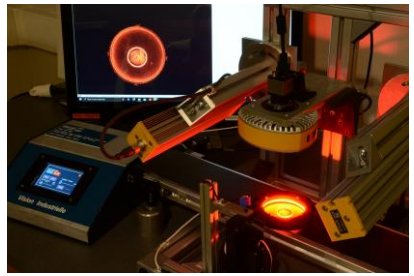

SC19 – Cameras and Interfaces

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

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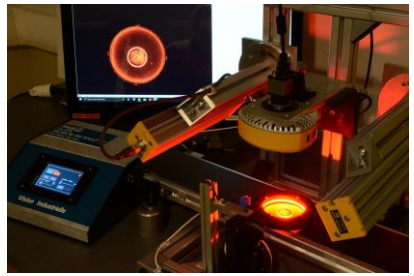
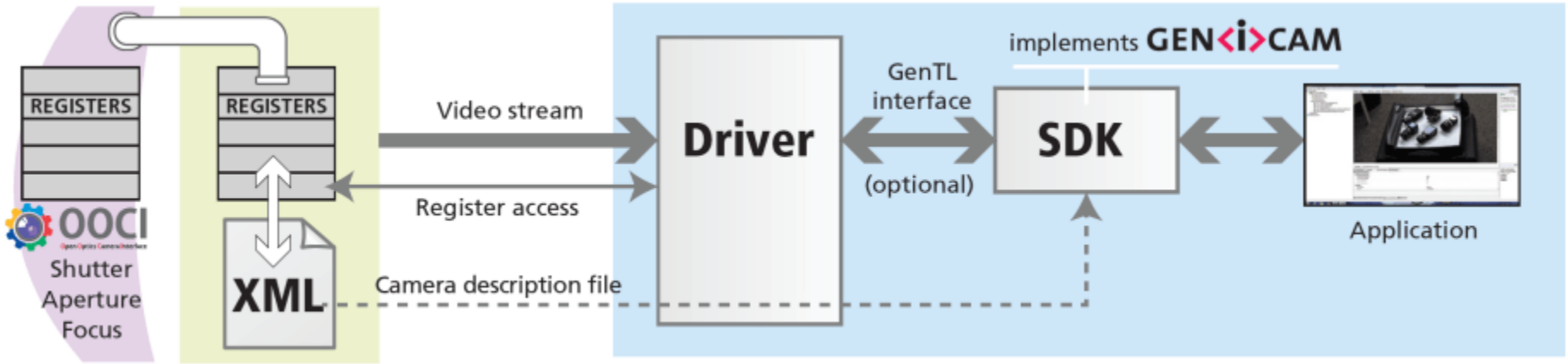


SC19 – Cameras and Interfaces

GeniCam ® : Generic Interface for Cameras

https://www.emva.org/standards-technology/genicam/introduction-new/

GeniCam® is a **generic programming interface** for all kinds of devices.
The application programming interface (API) will be identical regardless of interface technology.



GenApi defines the mechanism used to provide the generic API via a self-describing XML file in the device.

SFNC (Standard Features Naming Convention)
standardizes the name, type, meaning and use of device features

GenTL (Transport Layer) standardizes the transport layer programming interface (low-level API)
GenDC (Data Container) defines a portable Generic Data Container (GenDC) format
GenCP (Control Protocol) a low-level standard to define the packet format for device control

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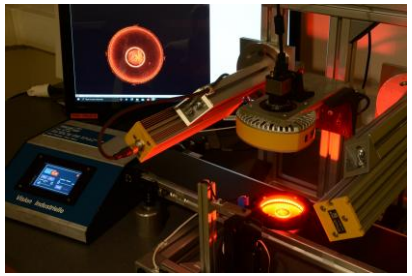

SC19 – Cameras and Interfaces

GeniCam ® : Generic Interface for Cameras

https://www.emva.org/standards-technology/genicam/introduction-new/

SFNC (Standard Features Naming Convention)
standardizes the name, type, meaning and use of device features

2.2 Image Format Control

Contains the features related to the format of the transmitted image (See the Image Format Control chapter for details).

Table 2-2: Image Format Control Summary

Name	Level	Interface	Access	Unit	Visibility	Description
ImageFormatControl	R	ICategory	R	-	B	Category for Image Format Control features.
SensorWidth	R	IInteger	R	-	E	Effective width of the sensor in pixels.
SensorHeight	R	IInteger	R	-	E	Effective height of the sensor in pixels.
SensorPixelWidth	O	IFloat	R	um	G	Physical size (pitch) in the x direction of a photo sensitive pixel unit.
SensorPixelHeight	O	IFloat	R	um	G	Physical size (pitch) in the y direction of a photo sensitive pixel unit.
SensorName	O	IString	R	-	G	Product name of the imaging Sensor.
SensorShutterMode	O	IEnumeration	R/(W)	-	G	Specifies the shutter mode of the device.
SensorTaps	O	IEnumeration	R/(W)	-	E	Number of taps of the camera sensor.
SensorDigitizationTaps	O	IEnumeration	R/(W)	-	E	Number of digitized samples outputted simultaneously by the camera A/D conversion stage.
WidthMax	R	IInteger	R	-	E	Maximum width of the image (in pixels).
HeightMax	R	IInteger	R	-	E	Maximum height of the image (in pixels).

*From the **SFNC 2.7 (PDF)***

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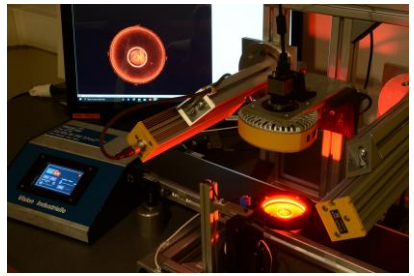

SC19 – Cameras and Interfaces

GeniCam ® : Generic Interface for Cameras

https://www.emva.org/standards-technology/genicam/introduction-new/

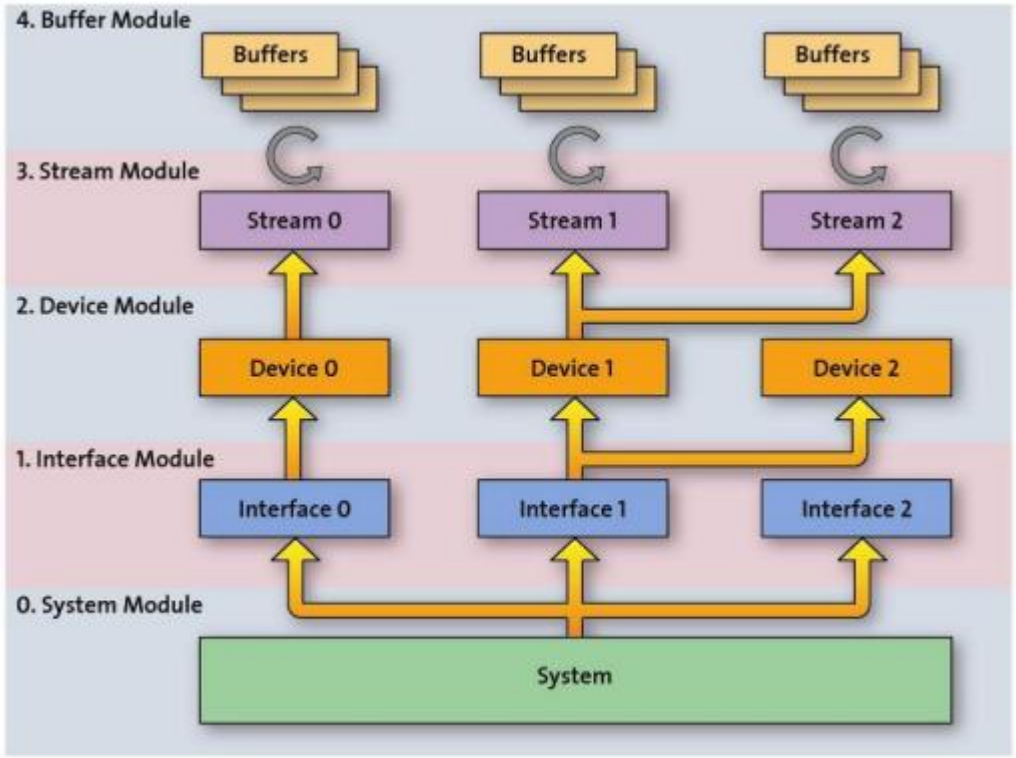

Figure 2-2: GenTL Module hierarchy

*From the **GenTL 1.6 (PDF)***

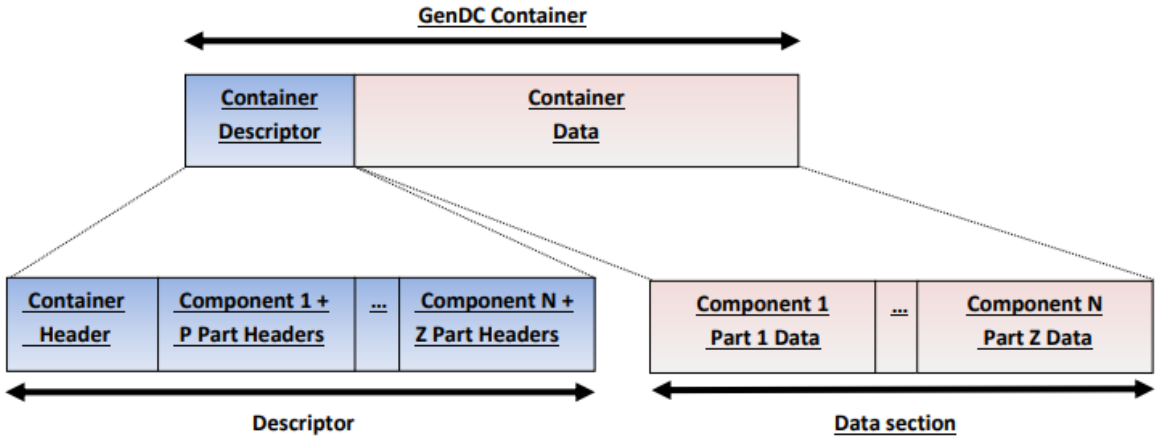

Figure 2-1: GenDC Container Descriptor and Data

*From the **GenDC 1.1 (PDF)***

GenTL (Transport Layer) standardizes the transport layer programming interface (low-level API)
GenDC (Data Container) defines a portable Generic Data Container (GenDC) format

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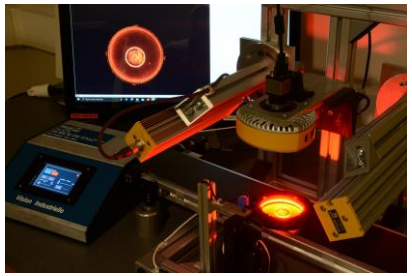
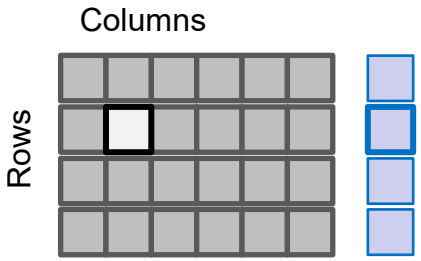


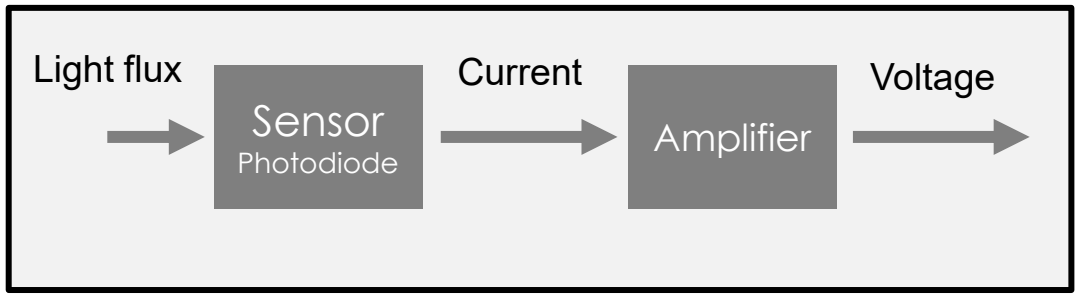
SC19 – Cameras and Interfaces

Dark Current



Dark Current

Response of the sensor to **complete darkness**



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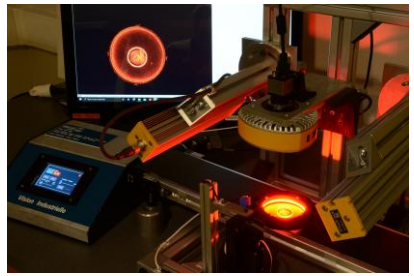
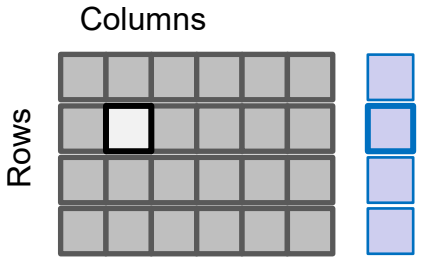


SC19 – Cameras and Interfaces

Black level : an offset to compensate electronic defaults

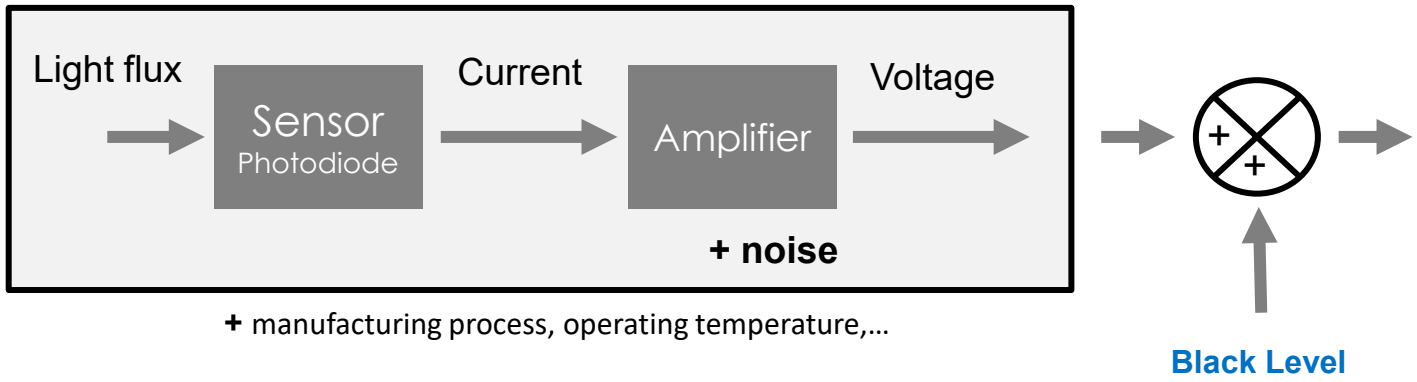


Dark Current

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

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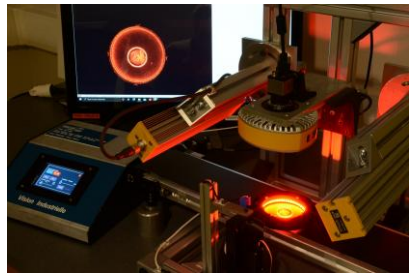
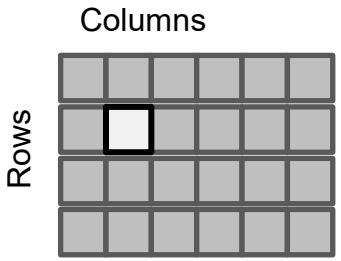
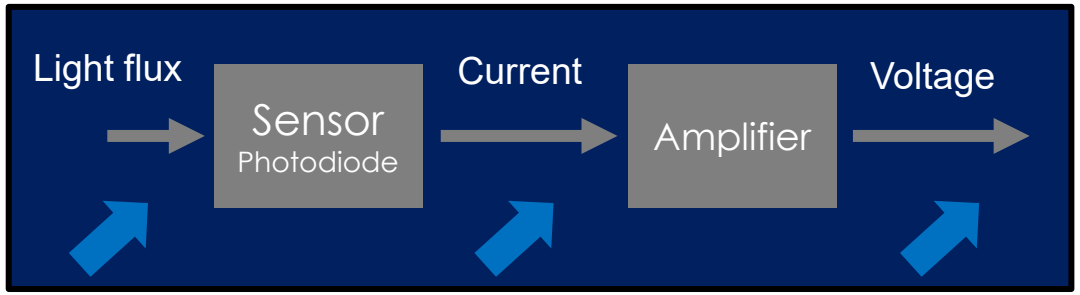
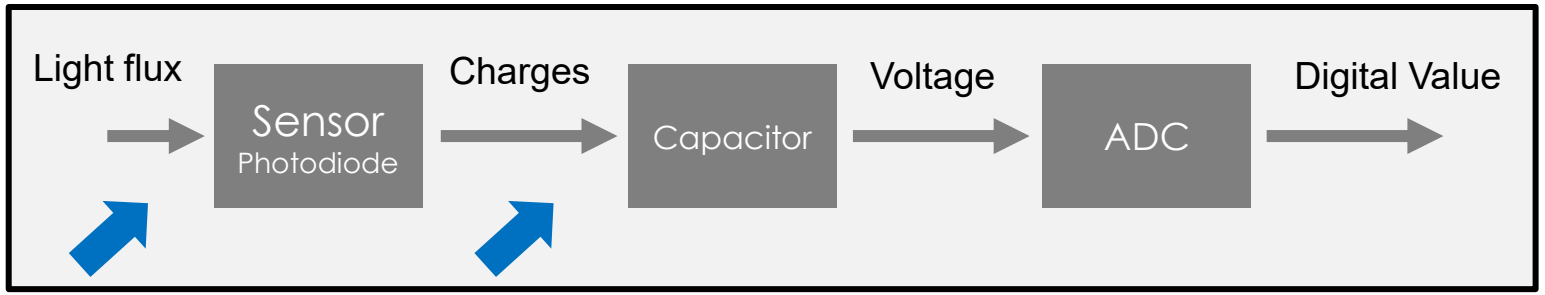


SC19 – Cameras and Interfaces

Exposure Time







Exposure Time

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This parameter determines the amount of light collected.

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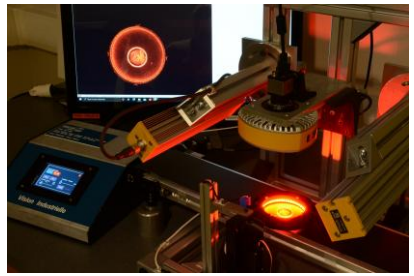
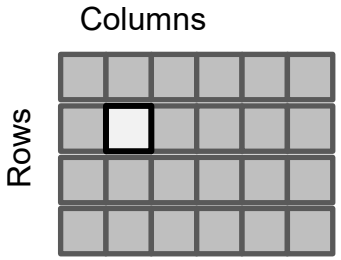
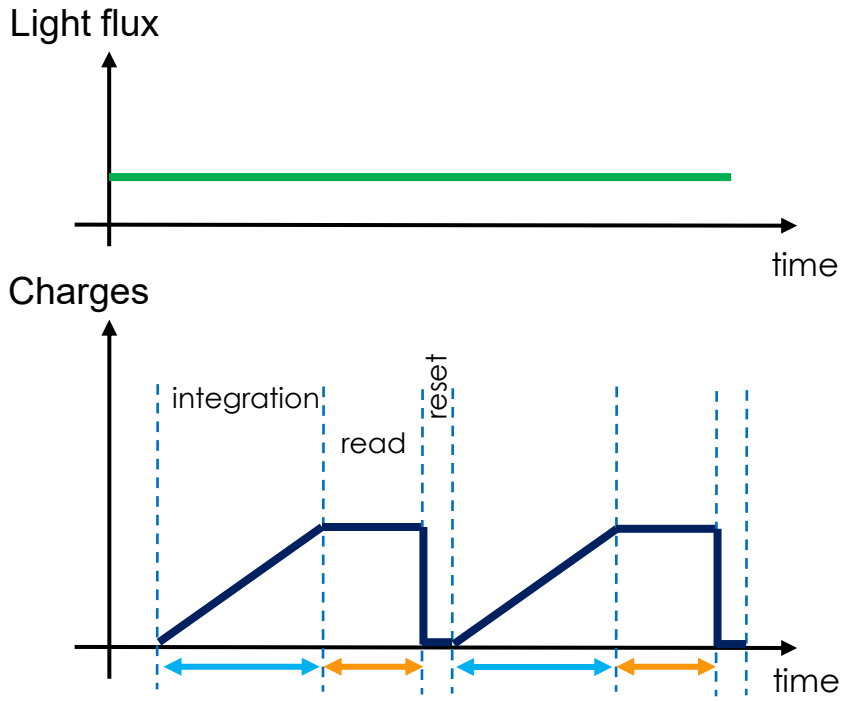


SC19 – Cameras and Interfaces

Exposure Time





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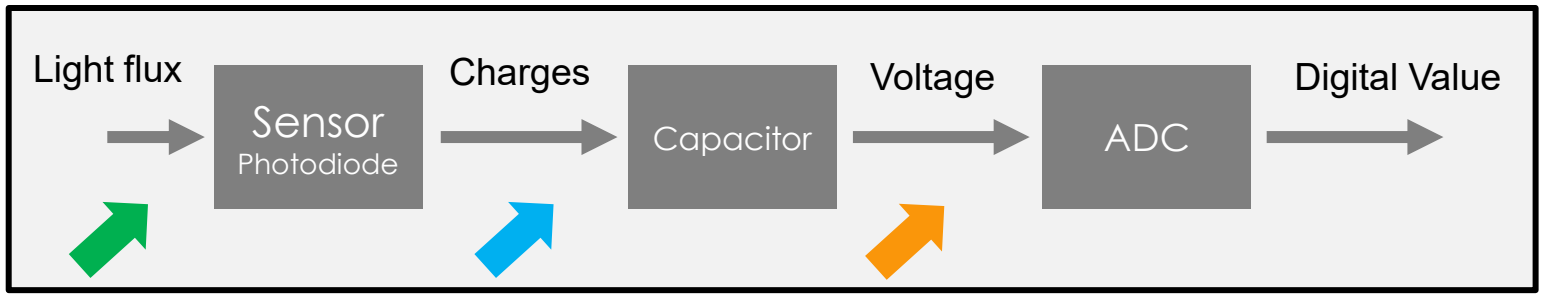
i.e. the amount of collected charges coming from the sensor stored in a capacitor



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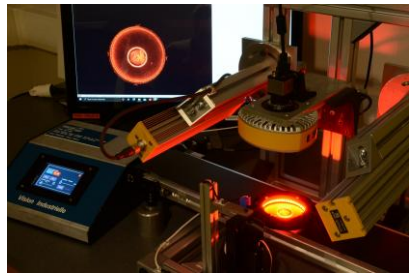
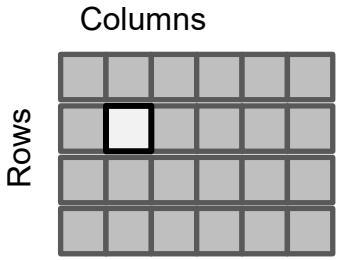
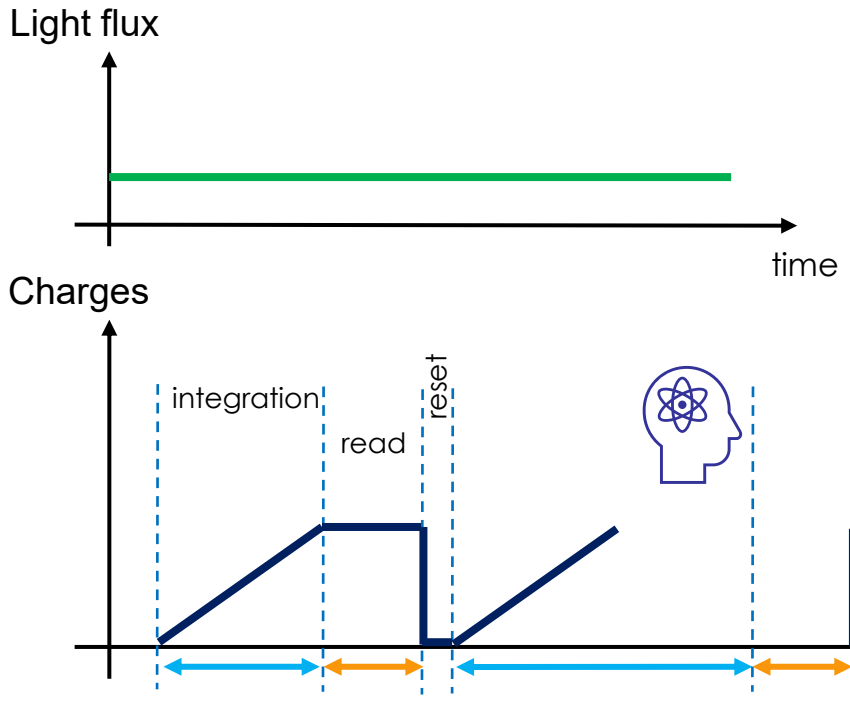


SC19 – Cameras and Interfaces

Exposure Time





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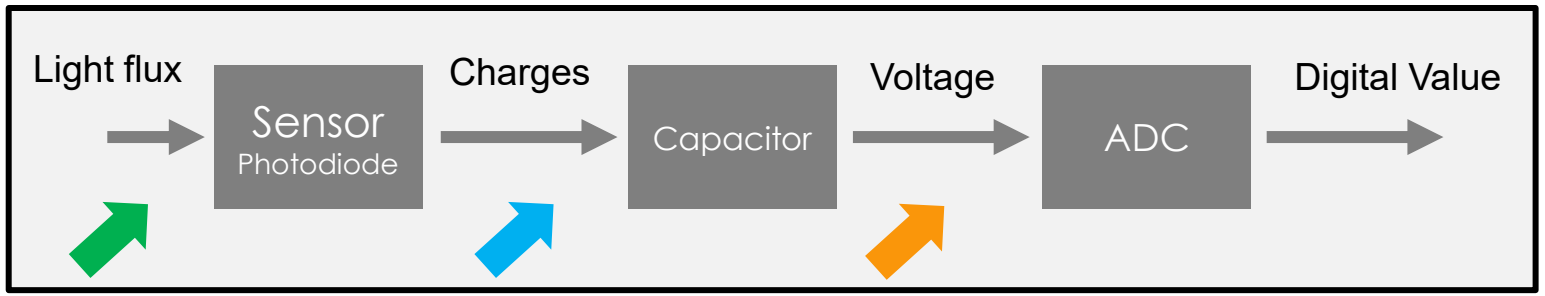

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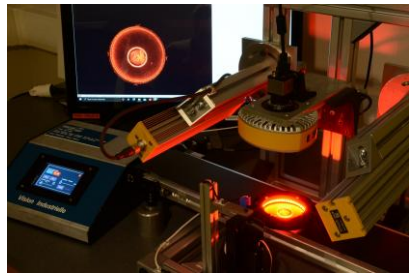

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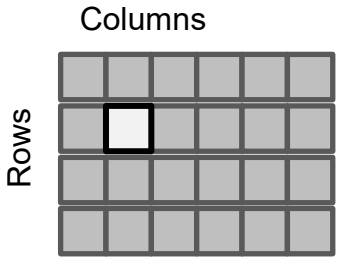

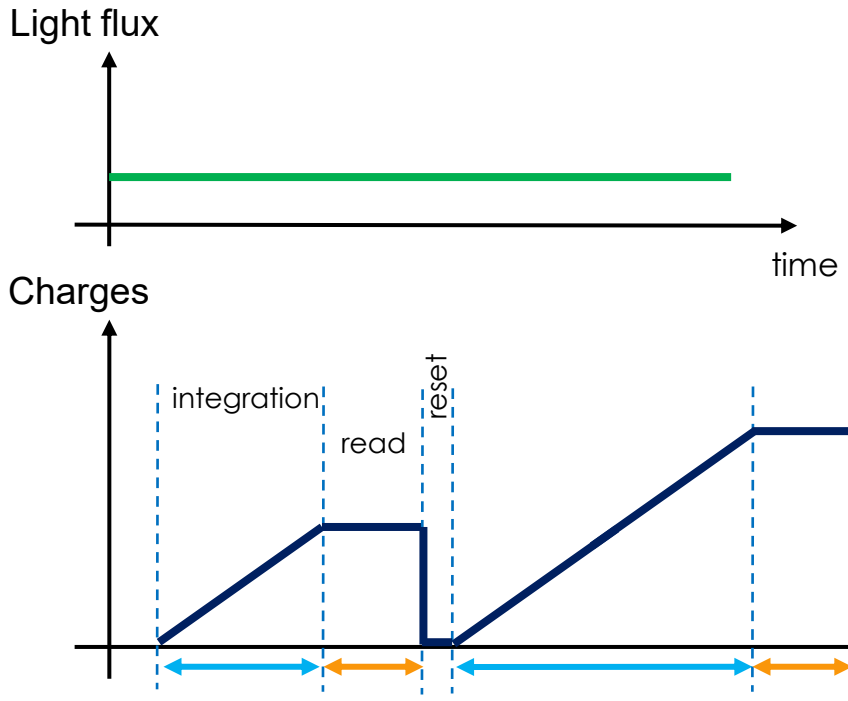

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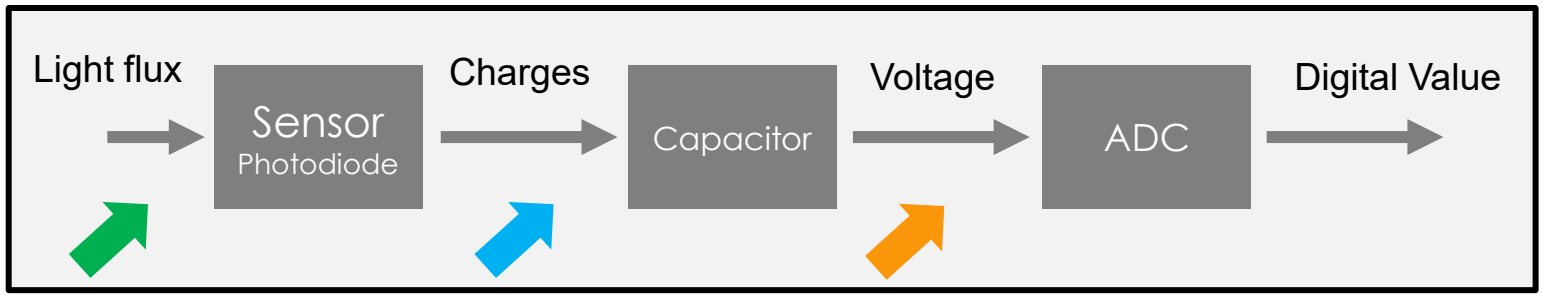

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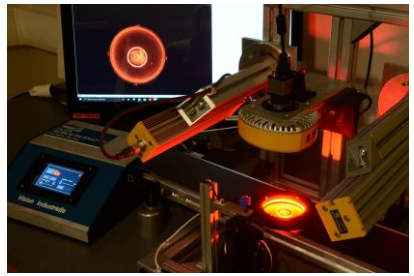

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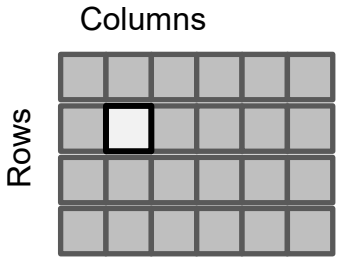

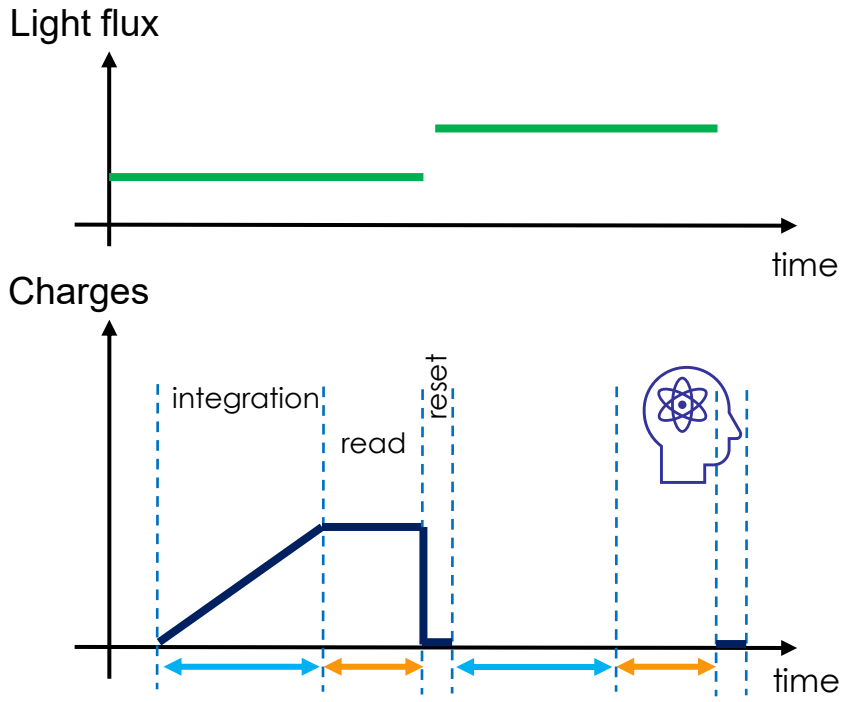

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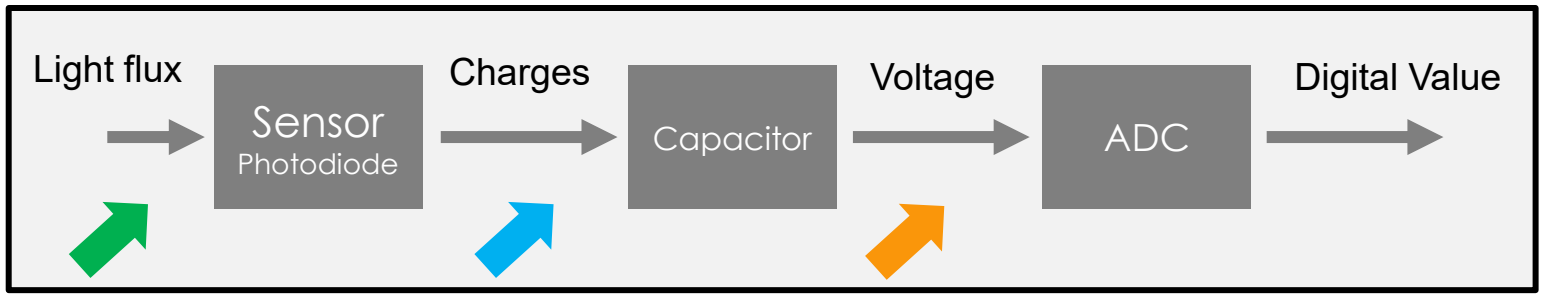

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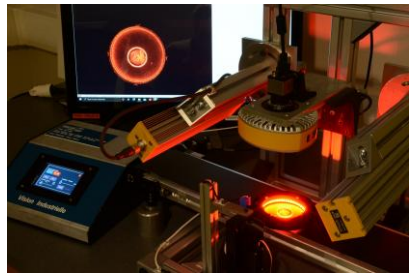

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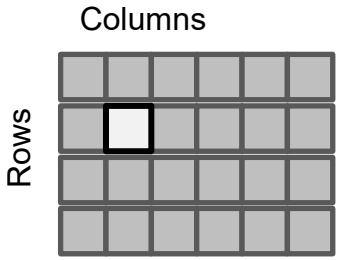

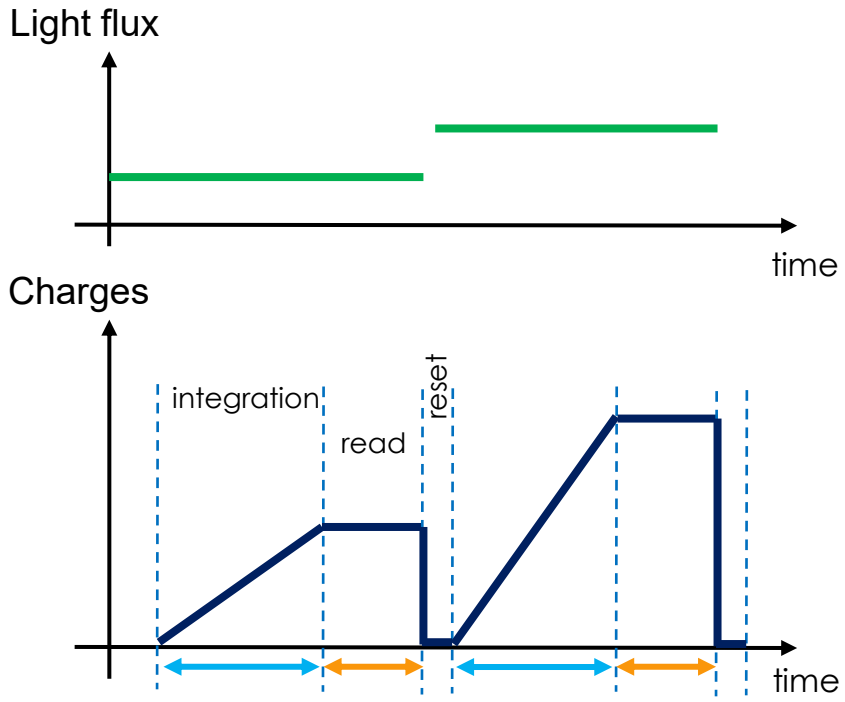

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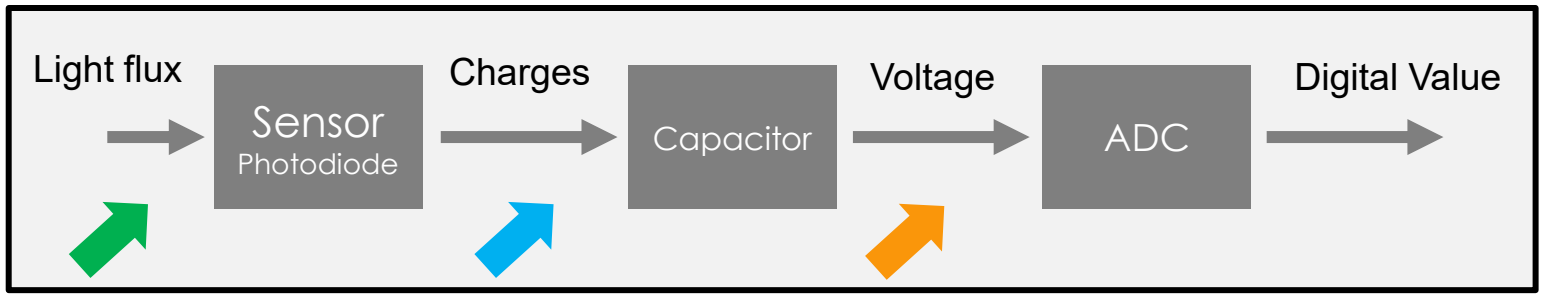

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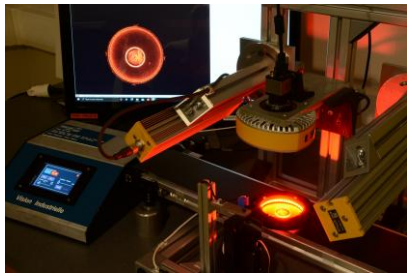

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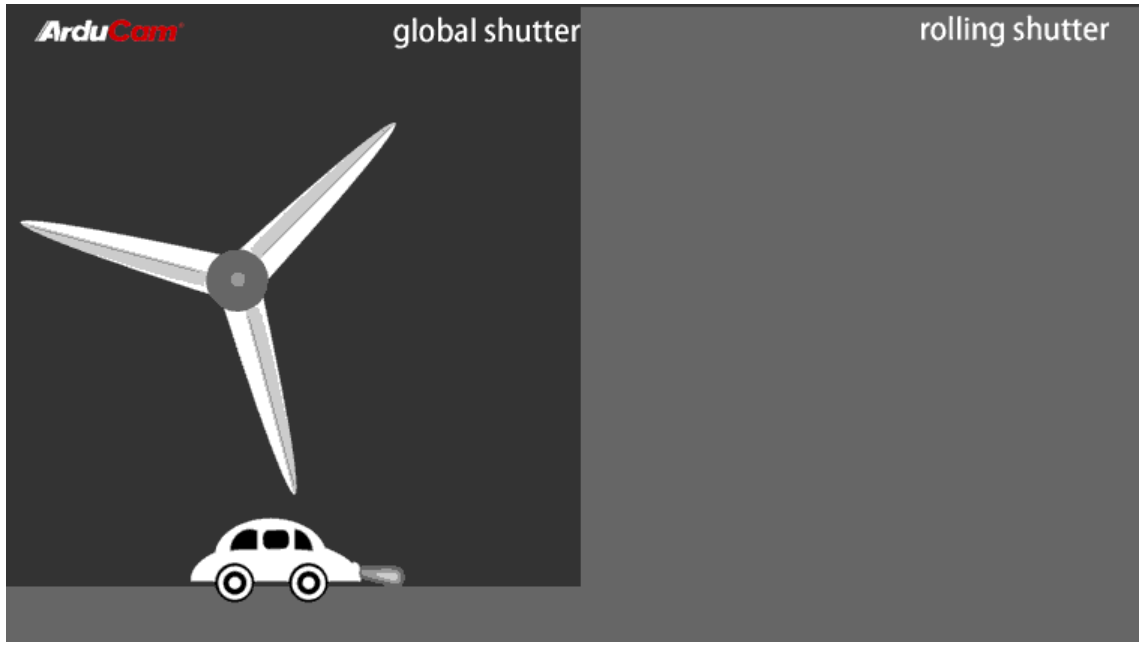
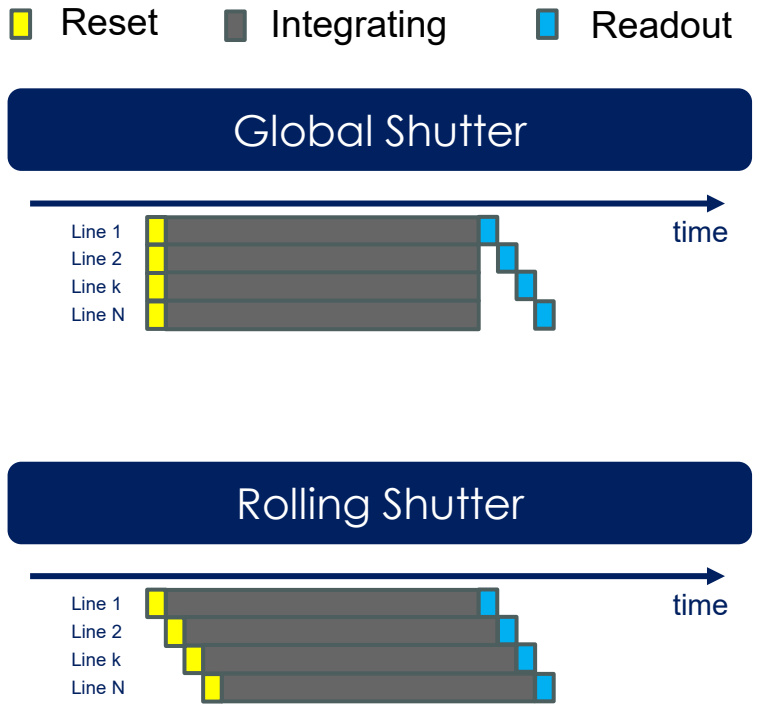
Shutter





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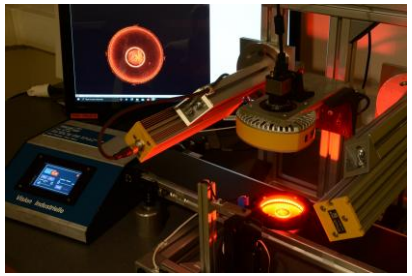


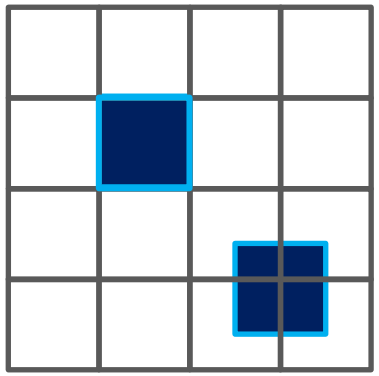
SC19 – Cameras and Interfaces

Spatial Resolution

Small object to detect

Spatial resolution / P

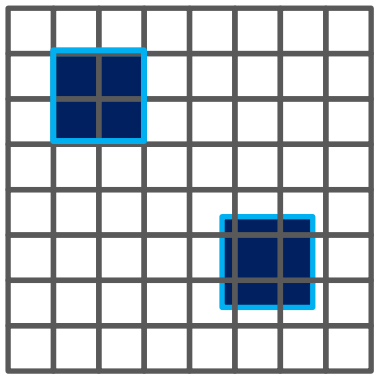
Distance observed by a single pixel in a given direction



$$P = d$$

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

And S >= 2



Security factor S

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

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

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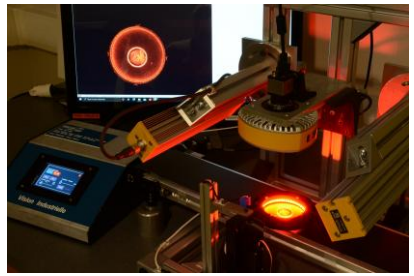
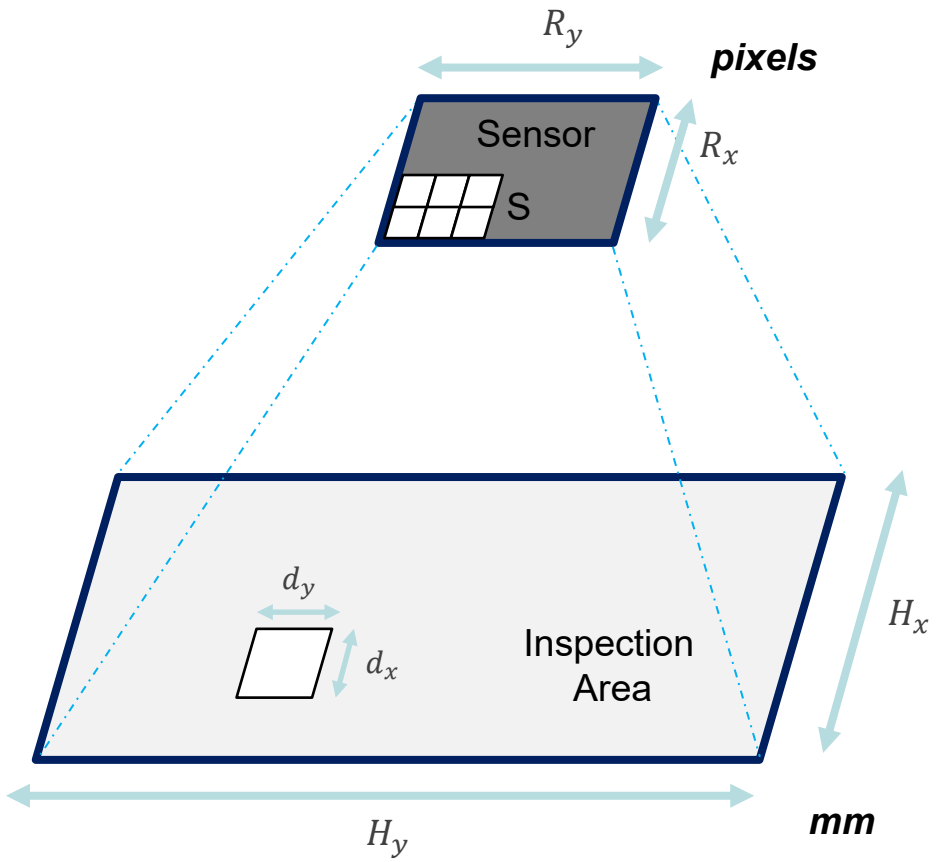


SC19 – Cameras and Interfaces

Resolution of the sensor



Spatial resolution / P

Distance observed by a single pixel in a given direction

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

Sensor resolution (pixels)

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

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

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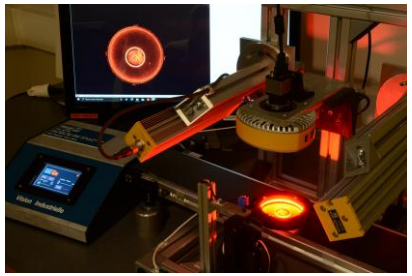
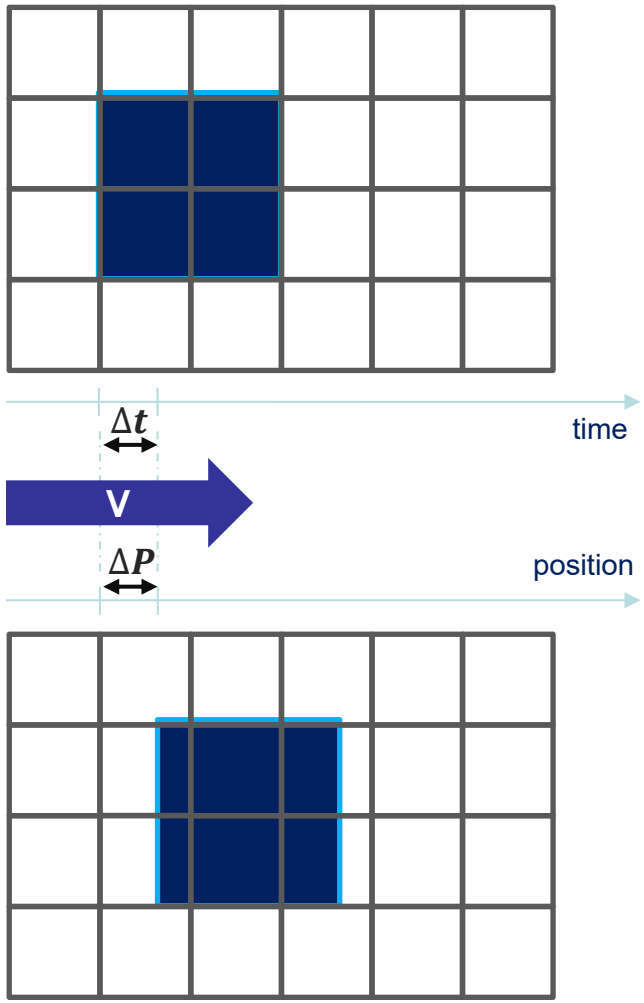


SC19 – Cameras and Interfaces

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

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

Displacement

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

Time

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

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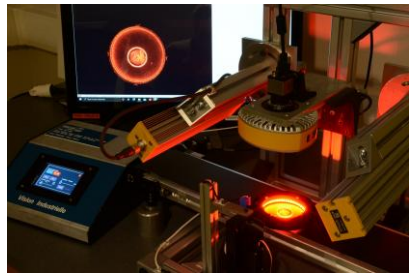
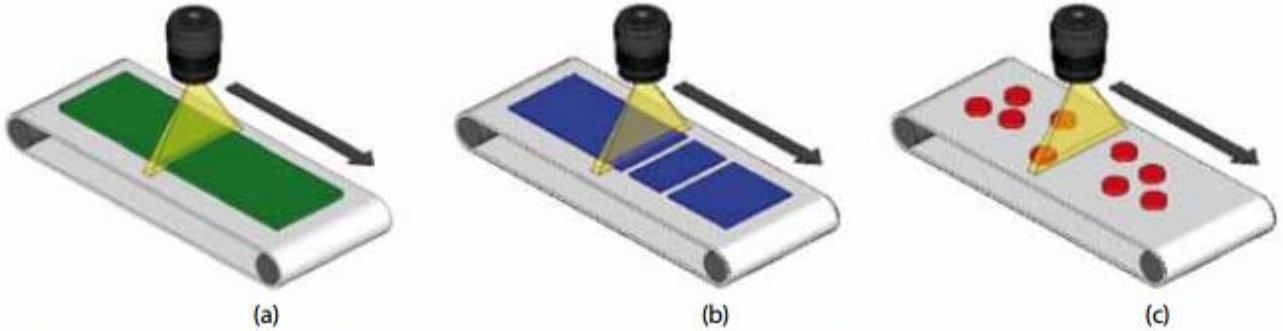


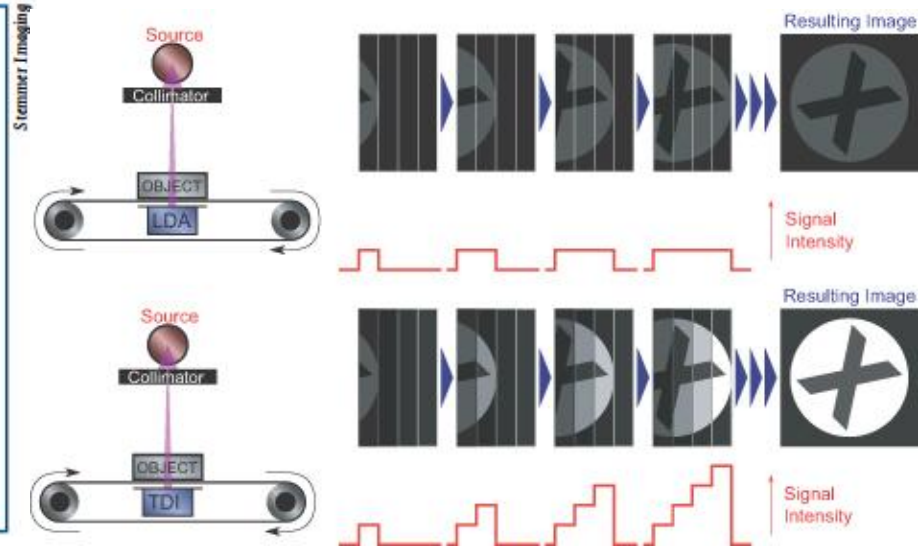
SC19 – Cameras and Interfaces

Linear Sensor

Les principales applications de la vision linéaire



Les caméras linéaires sont couramment utilisées dans l'inspection de produits en défilement continu (a) ou dans le contrôle de produits de longueur variable (b). L'acquisition, effectuée ligne par ligne, est en effet indépendante de la longueur de l'objet ou de ses proportions. On utilise aussi la technologie linéaire pour le contrôle de produits en vrac (c). Il n'est pas nécessaire de "recoller" plusieurs images successives au moment du traitement.



https://x-scanimaging.com/detectors/xti90802/

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