Cameras for Machine Vision

Institut d'Optique – Engineers Training

Semester 6 – Digital Interface

Julien VILLEMEJANE

Cameras for Machine Vision
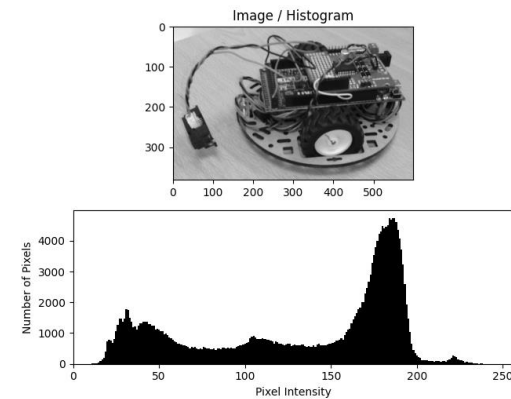
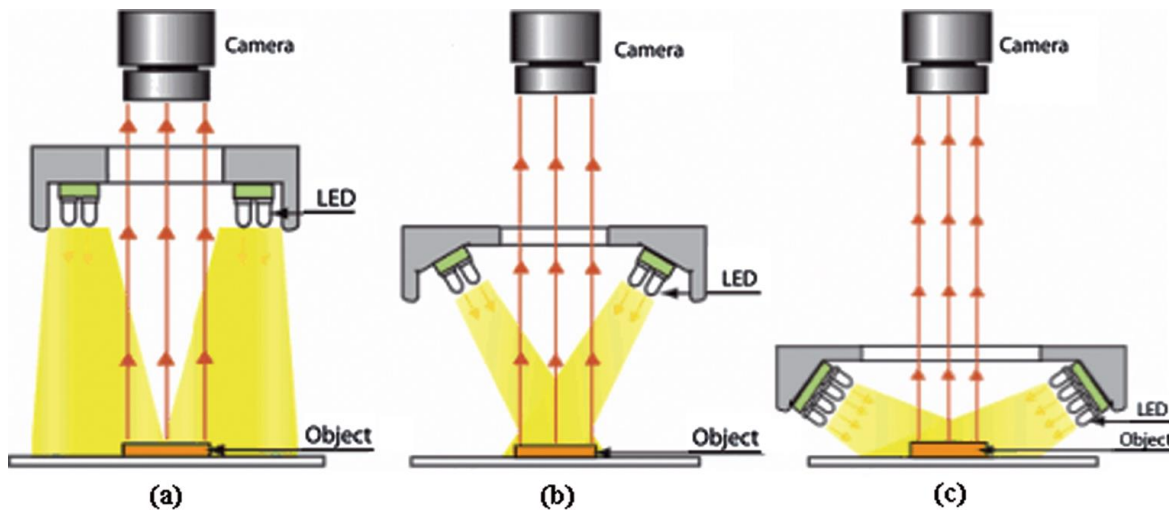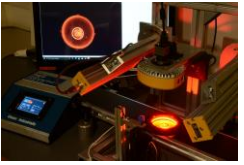At the end of this training, the learners will be able to:

Describe

Resolution, bit depth

Exposure Time, Black level

Digital Image, data transfer
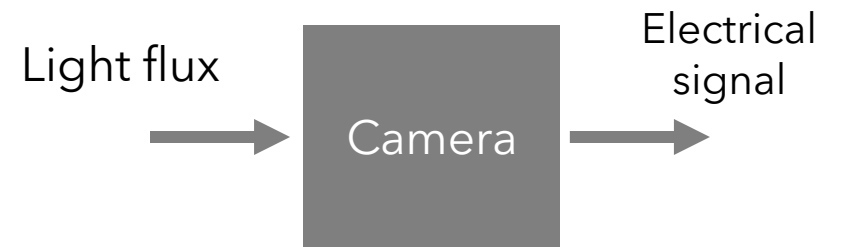
(a)   (b)   (c)

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

Camera : anatomy of a 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)	

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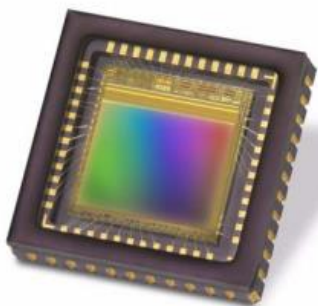Size / Form factor
Lens compatibility
Shutter Type

Interface

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

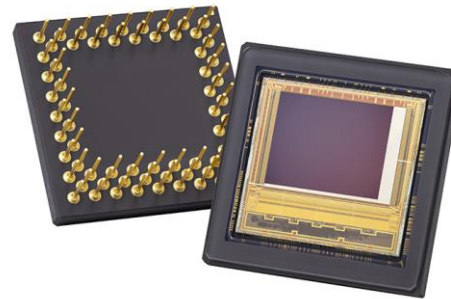| Parameter		Unit	Typical value	
Sensor characteristics	Resolution	pixels	1280 (H) × 1024 (V)	
	Image size	mm / inches	6.9 (H) × 5.5 (V) - 8.7 (diagonal) / ≈ 1/1.8	
	Pixel size (square)	µm	5.3 × 5.3	
	Aspect ratio		5 / 4	
	Max frame rate	fps	60 @ full format	
	Pixel rate	Mpixels / s	90 -> 120	
	Bit depth	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]	mW	< 200 mW	
	Standby	µW	180	

e2v sensor EV76C560ACT

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

Parameter		Unit	Typical value	
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Pixel performance			**@ 25°C**	**@ 65°C**
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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.
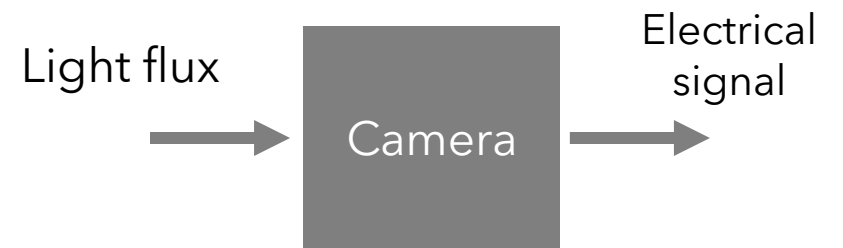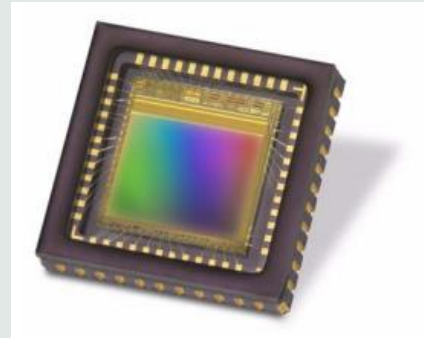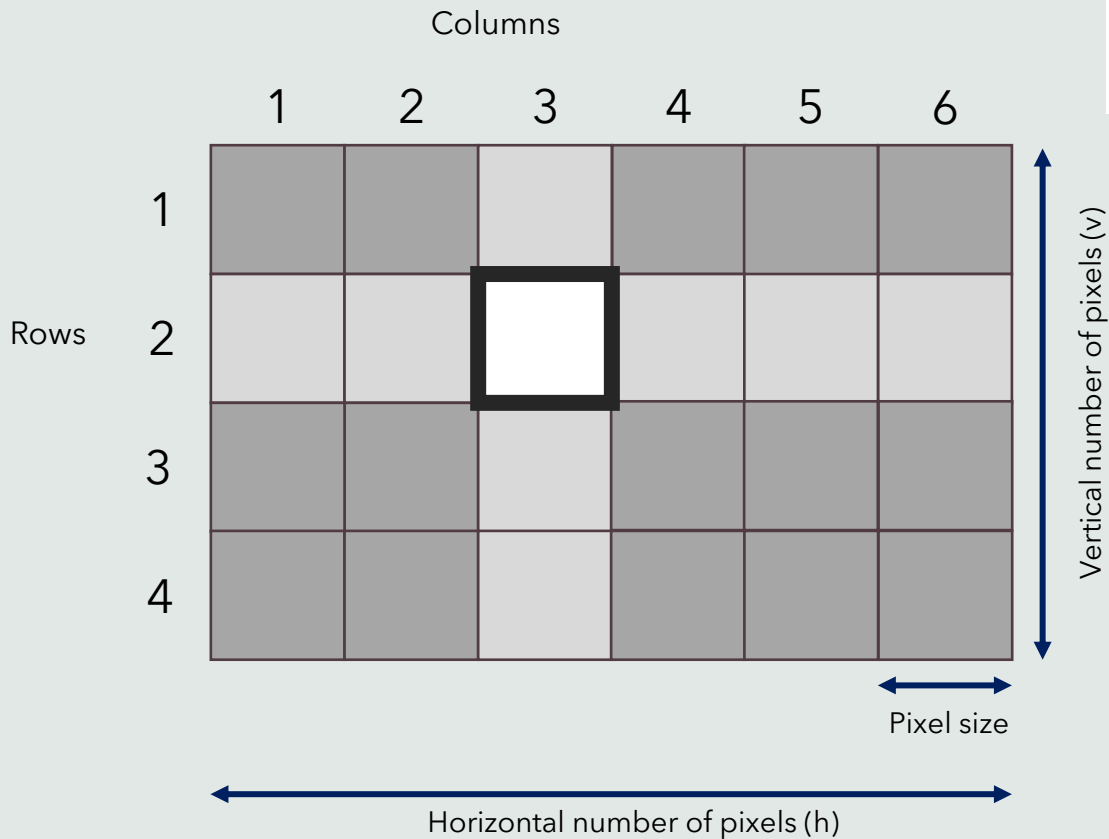
Camera : array of small sensors

Columns

	1	2	3	4	5	6
1						
2						
3						
4						

Rows

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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Camera : array of small sensors

e2v sensor EV76C560ACT

Capteur	
Type de capteur	CMOS Couleur
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Taille de pixel	5,3 µm
Fabricant	e2v
Désignation du capteur	EV76C560ACT
Amplification (complet/RVB)	4x/4x

Columns

Rows

1   2   3   4   5   6

1

2

3

4

Vertical number of pixels (v)

Pixel size

Horizontal number of pixels (h)

Resolution
Size / Form factor

Camera : Bayer filter for color sensor
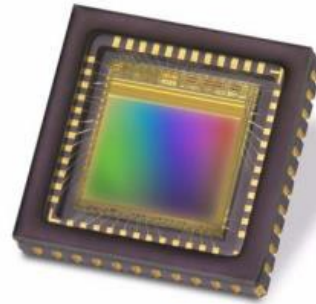
e2v sensor EV76C560ACT
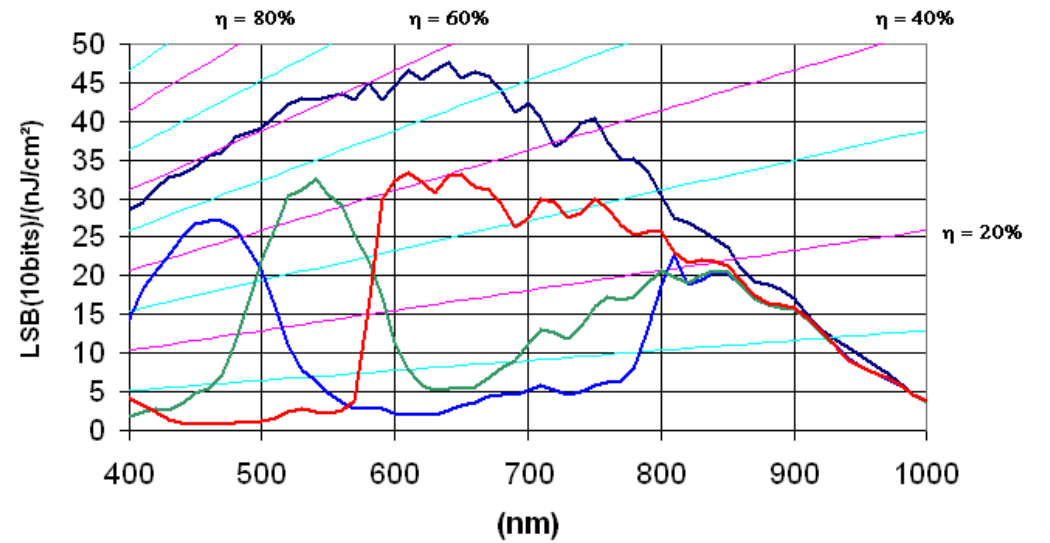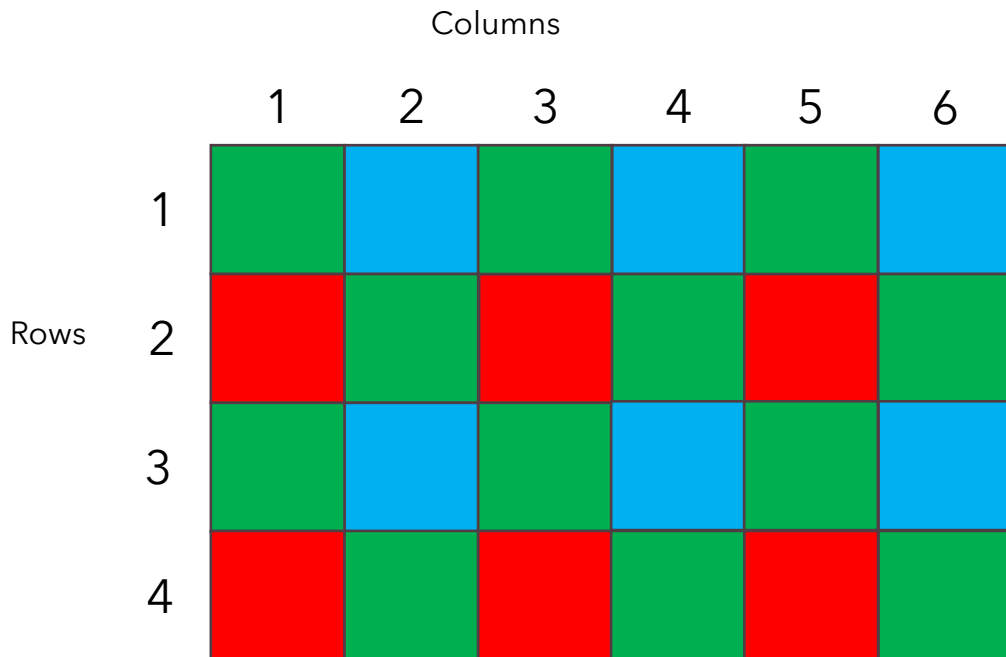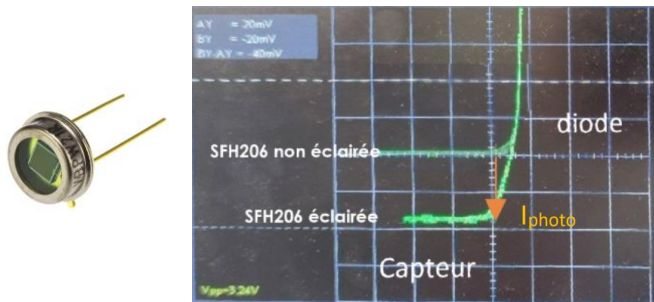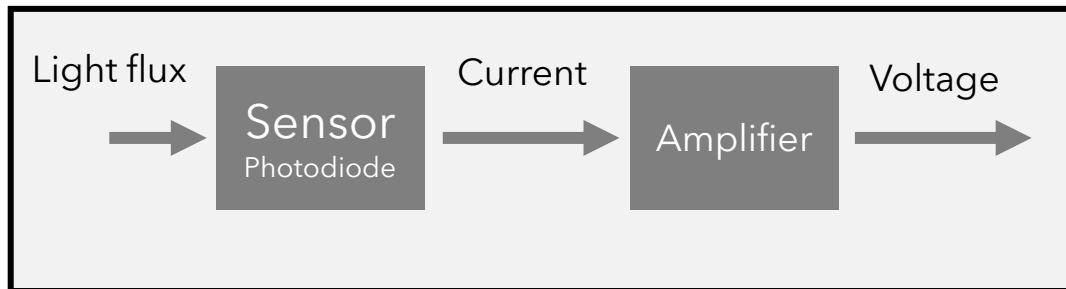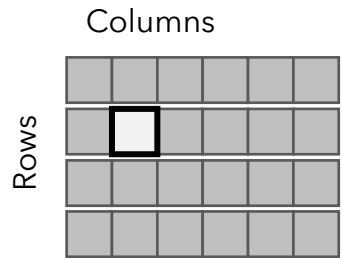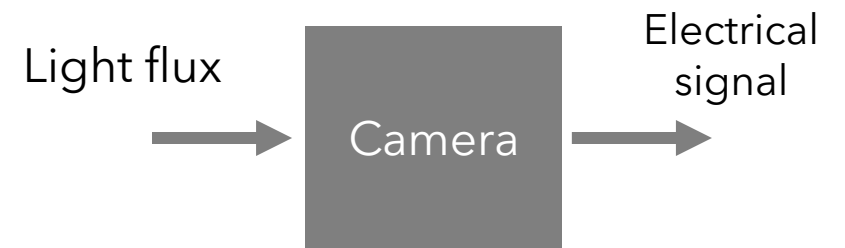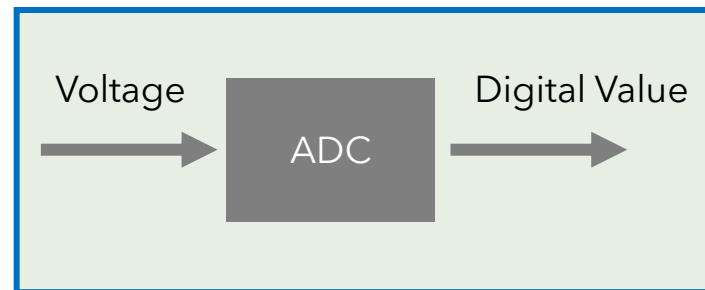
Columns

Rows

Columns

Rows

Light flux → **Sensor** Photodiode → Current → **Amplifier** → Voltage →

diode

SFH206 non éclairée

SFH206 éclairée   I_photo

Capteur

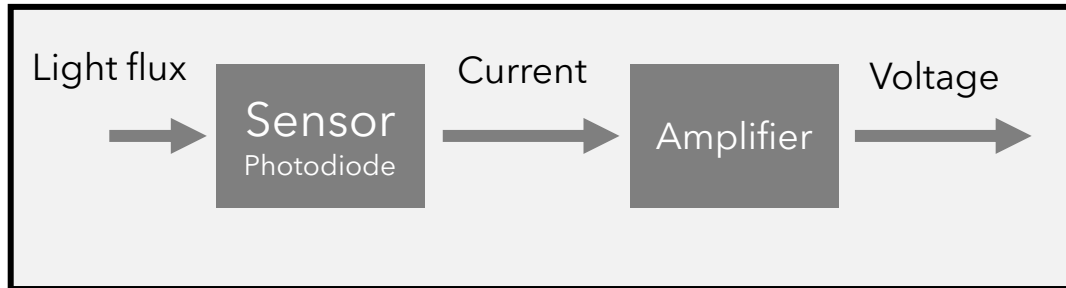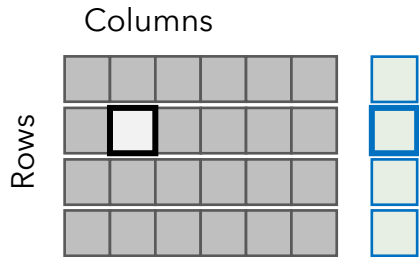## Camera

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

Light flux → Camera → Electrical signal

Columns

Rows

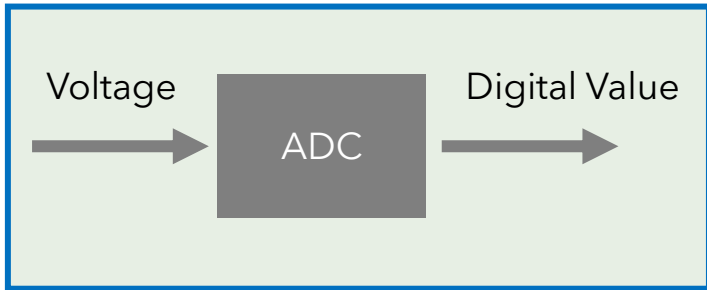Light flux → Sensor Photodiode → Current → Amplifier → Voltage →

Voltage → ADC → Digital Value →

Digital Camera

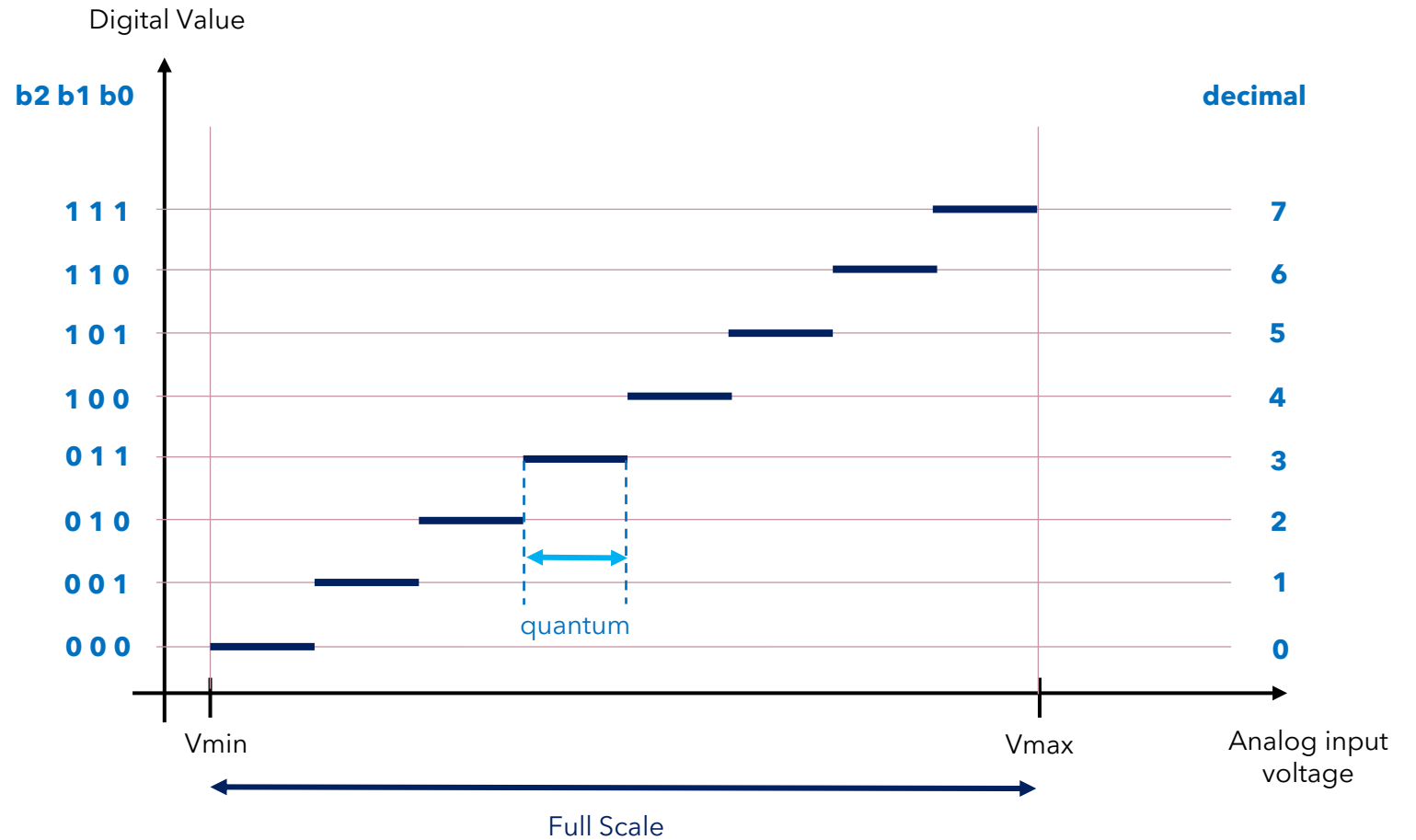Device that transforms an array of **light flux sensors** into **digital data** called pixels

Light flux → Camera → Digital Data

Example for n = 3 bits

Quantification

Voltage → ADC → Digital Value

Digital Outputs

Analog Input → ADC → bn, b2, b1, b0 } n bits

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.

Digital Value

b2 b1 b0   decimal

1 1 1	7
1 1 0	6
1 0 1	5
1 0 0	4
0 1 1	3
0 1 0	2
0 0 1	1
0 0 0	0

quantum

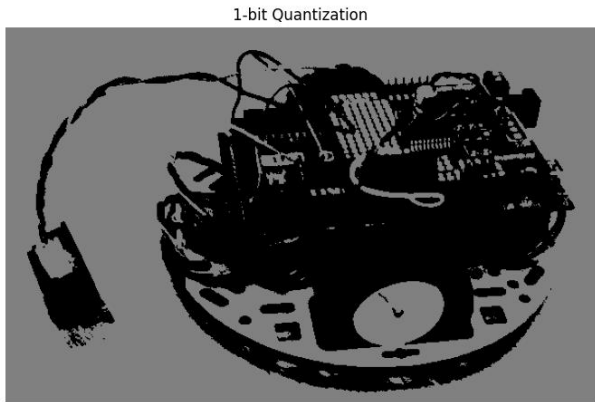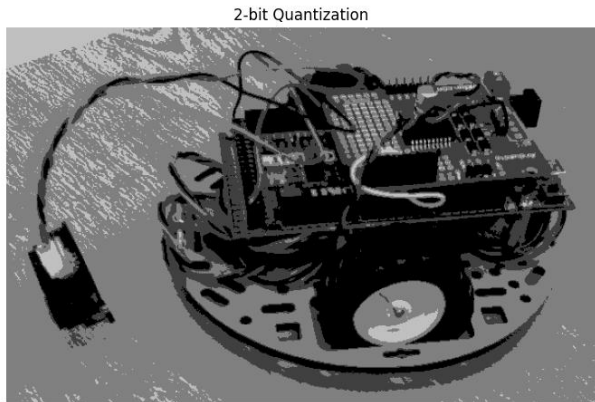Vmin   Vmax   Analog input voltage

Full Scale

How an Analog to Digital Converter works ?
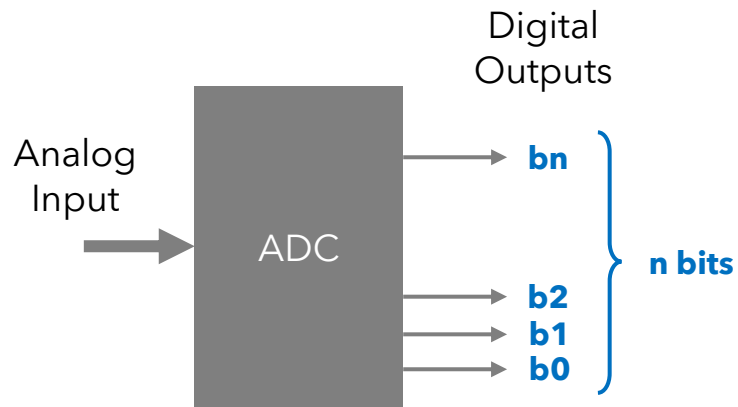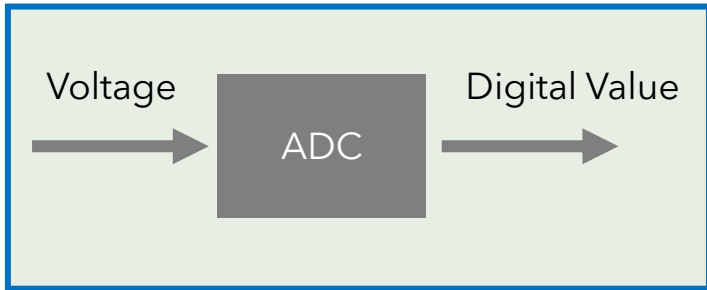
Quantification

Voltage → ADC → Digital Value

Analog Input → ADC → Digital Outputs
b_n
b_2
b_1
b_0
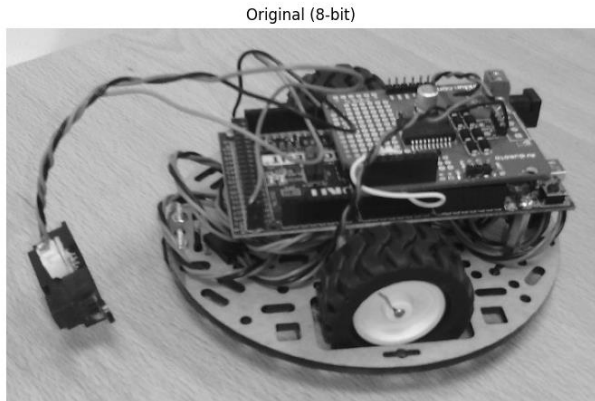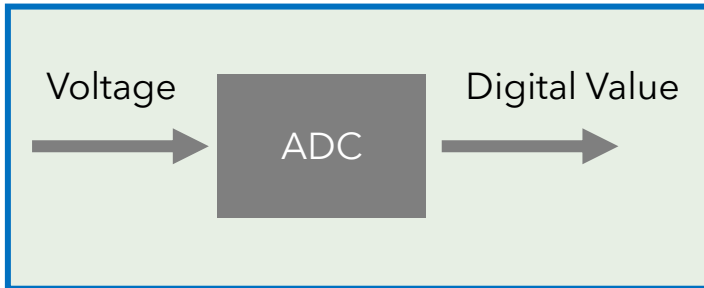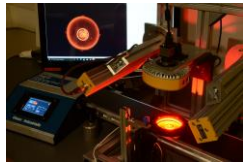n bits

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

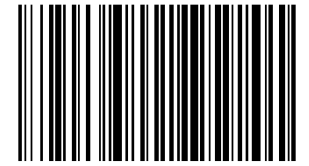The **number of different values** that can be represented by **n bits** is 2^n.

Original (8-bit)

4-bit Quantization

2-bit Quantization

1-bit Quantization

Voltage → **ADC** → Digital Value
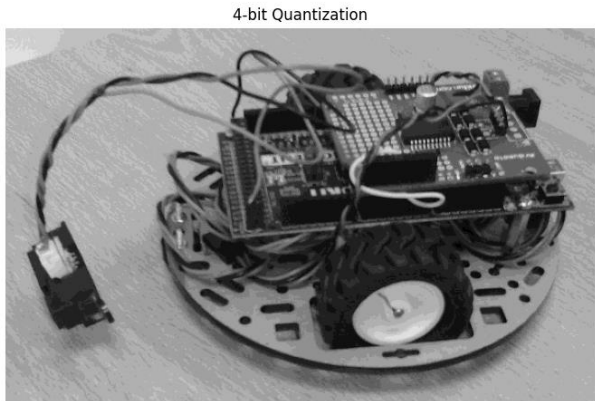
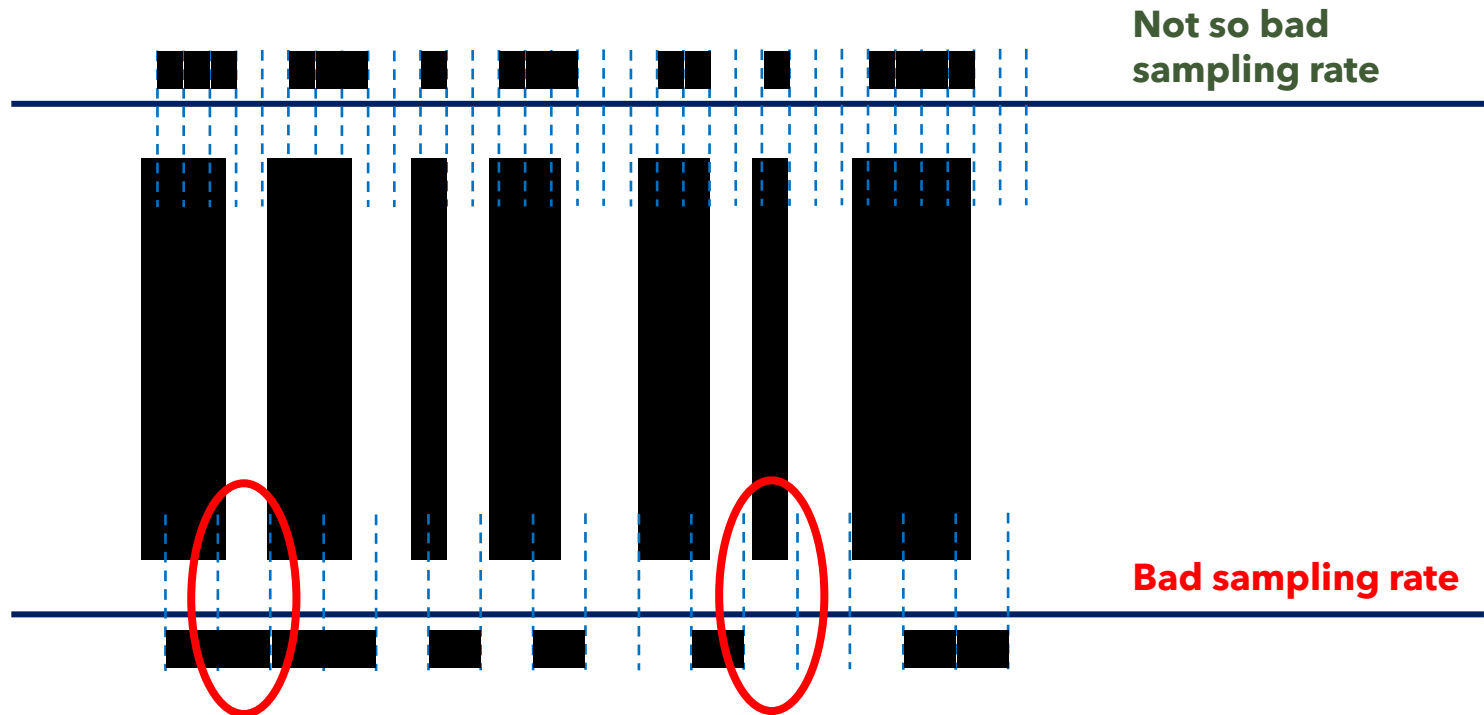## Sampling

Barcode to decode

LEnsE 2024

Area of sampling

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.*

Not so bad sampling rate

Bad sampling rate

Sampling and quantification of an image
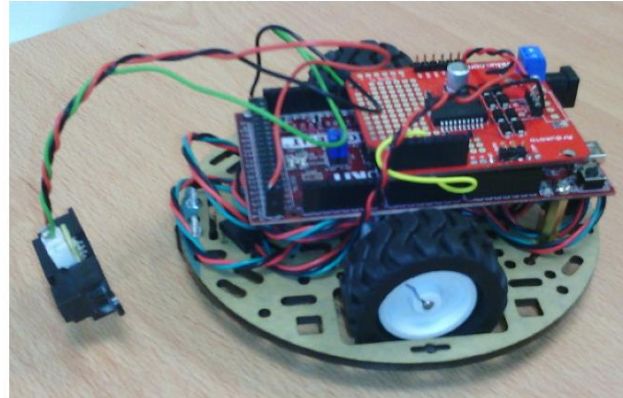

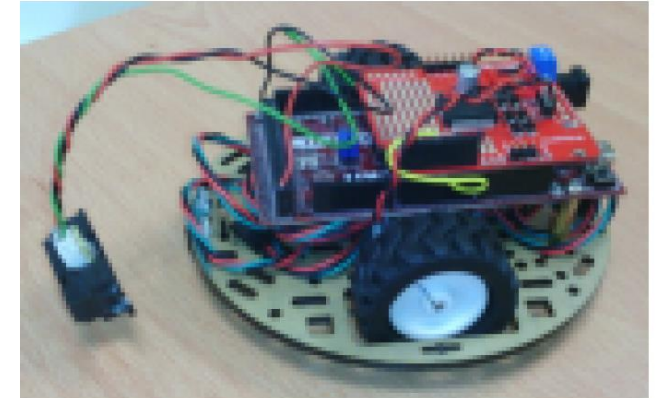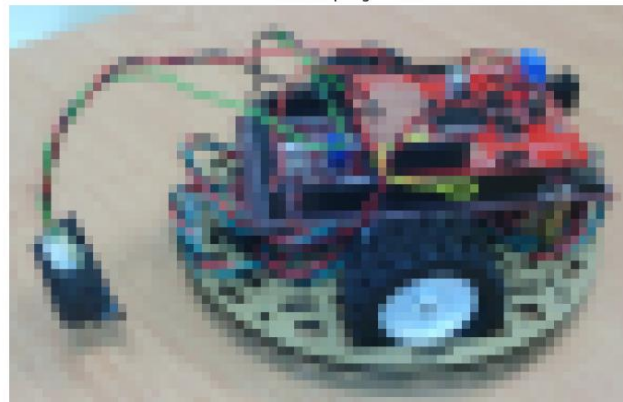Voltage → ADC → Digital Value

Sampling

Original Image

4x Sampling

8x Sampling

16x Sampling

Camera : array of small sensors

The **number of different values** that can be represented by **10 bits** is 2^{10} = **1024**
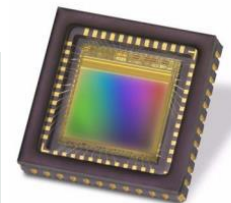
In a *Grayscale mode* :
- a **black pixel** is represented by **0**
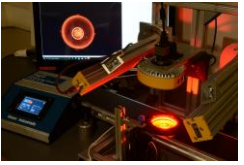- a **white pixel** is represented by **1023**

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

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

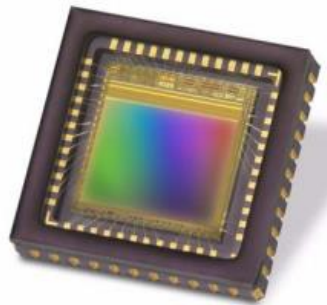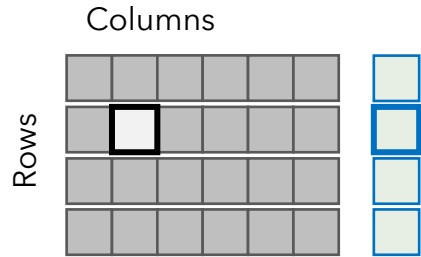| Parameter		Unit	Typical value	
Sensor characteristics	Resolution	pixels	1280 (H) × 1024 (V)	
	Image size	mm inches	6.9 (H) × 5.5 (V) - 8.7 (diagonal) ≈ 1/1.8	
	Pixel size (square)	µm	5.3 × 5.3	
	Aspect ratio		5 / 4	
	Max frame rate	fps	60 @ full format	
	Pixel rate	Mpixels / s	90 -> 120	
	Bit depth	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]	mW	< 200 mW	
	Standby	µW	180	

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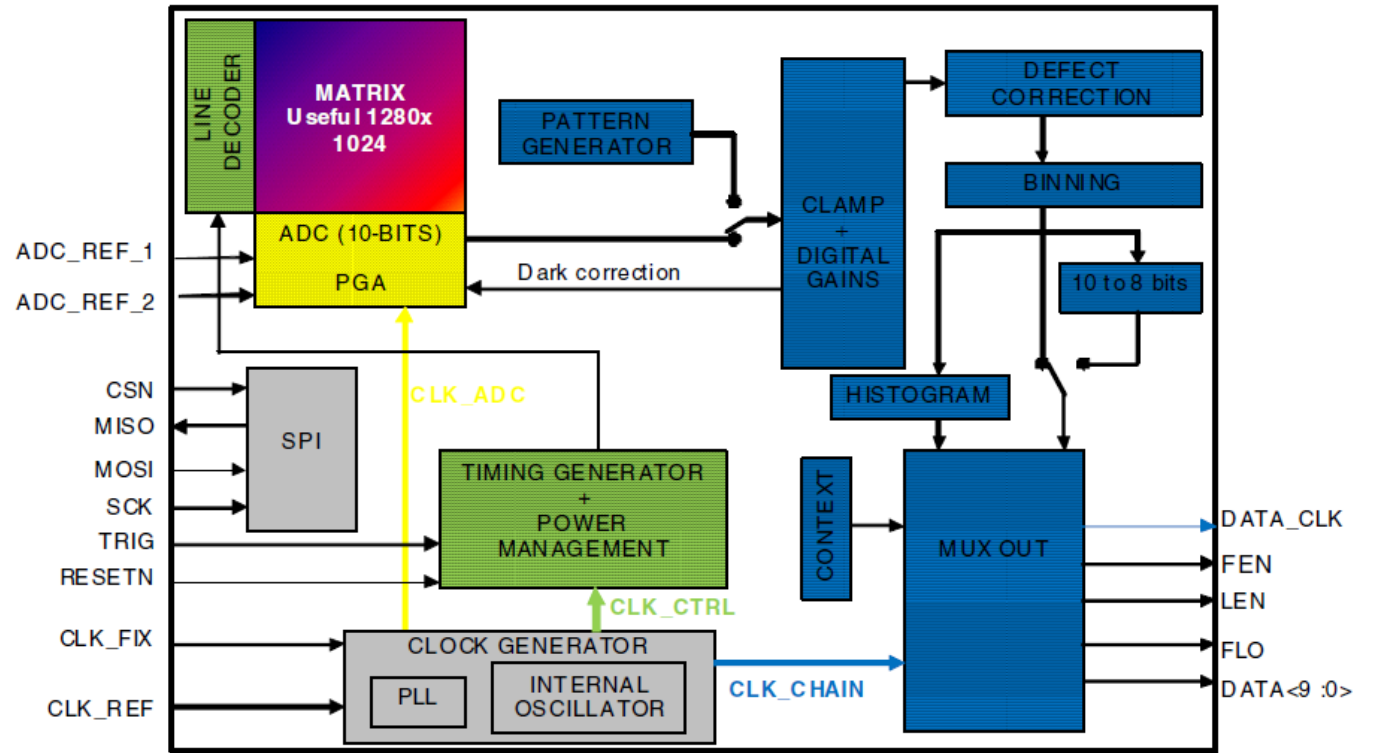4. @ 60 fps, full format, with 10 pF on each output.

Columns

Rows

e2v sensor EV76C560ACT

Columns

Rows

v

h

n bits

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**

Amount of data per image

Columns

Rows

v

h

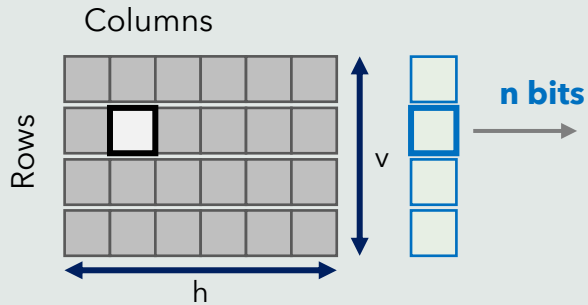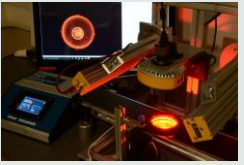n bits

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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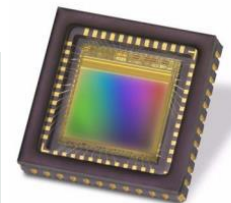
Each image has a total amount of binary data :

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)

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

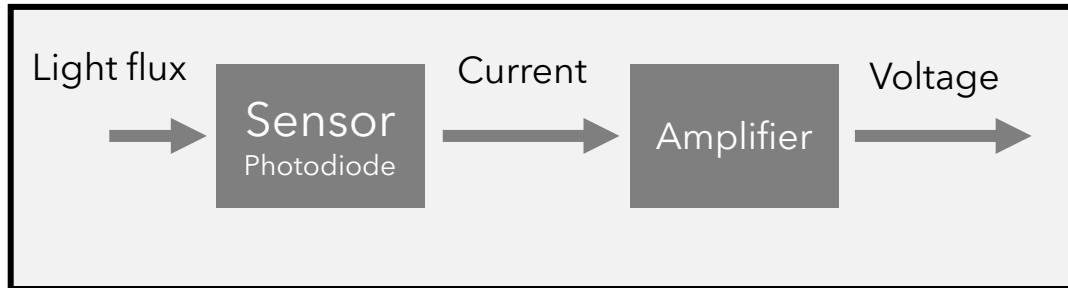|	USB 3.0	10 GigE	CameraLink	Coaxpress
Bandwith	5 to 20 Gbit/s	1.2 Gbits/s	Base : 2 Gbits/s Full : 5.4 Gbits/s (2 cables)	12.5 Gbits/s per cable
Cable length	3 m	100 m	7 to 15 m	20 to 40 m
Power	4.5 to 25 W	30 W *	Optional	13 W / cable
Frame Grabber	Not Required	Not Required	Required	Required
GeniCam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

Columns

Rows

Dark Current

Response of the sensor to **complete darkness**

Light flux → Sensor Photodiode → Current → Amplifier → Voltage →

Columns

Rows
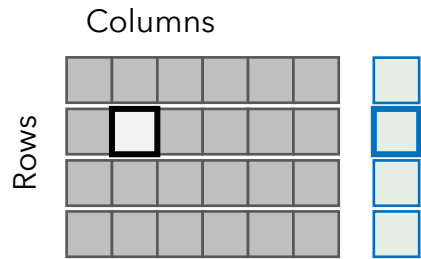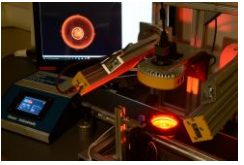
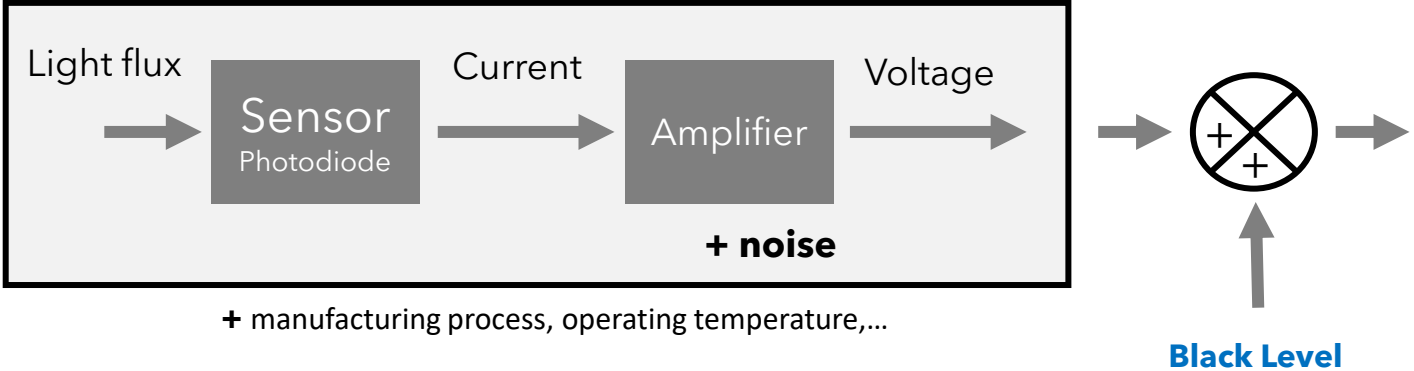## Dark Current

Response of the sensor to **complete darkness**

Black Level

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

Light flux → **Sensor** Photodiode → Current → **Amplifier** → Voltage → ⊗ →

+ noise

+ manufacturing process, operating temperature,...

Black Level

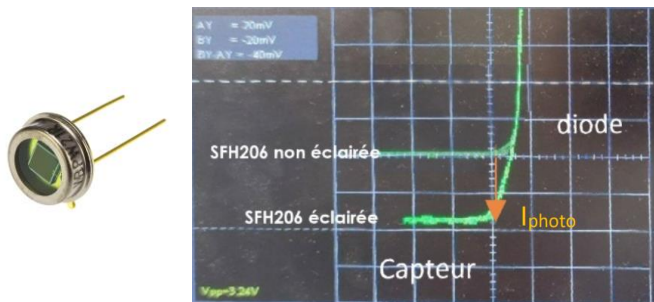*Adjusting the camera's black level will result in **an offset to the pixel's gray values** output by the camera.*

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

Columns

Rows

Light flux → Sensor Photodiode → Current → Amplifier → Voltage →
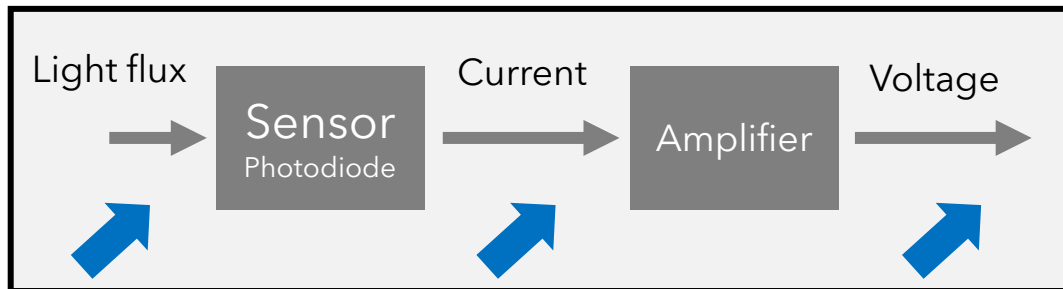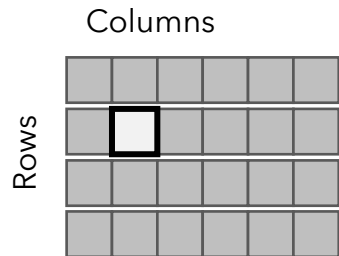
Exposure Time
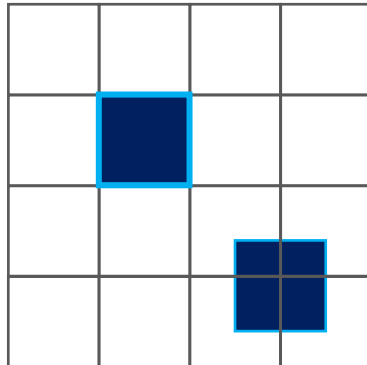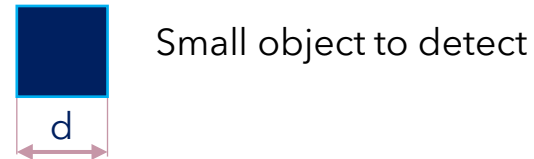
Duration for which the **camera's sensor is exposed to light**, when capturing an image.

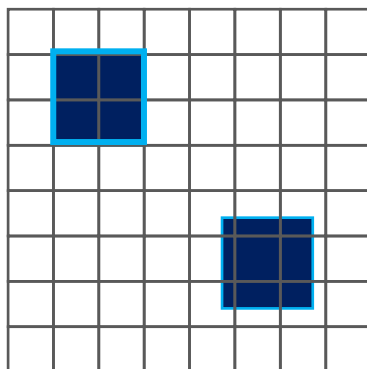*This parameter determines the amount of light collected.*

AY = 20mV
BY = -20mV
BY-AY = 40mV

diode

SFH206 non éclairée

SFH206 éclairée I_{photo}

Capteur

$V_{pp}=3.24V$

Small object to detect

d

$$P = d$$

Security factor S

$$P = \frac{d}{S}$$
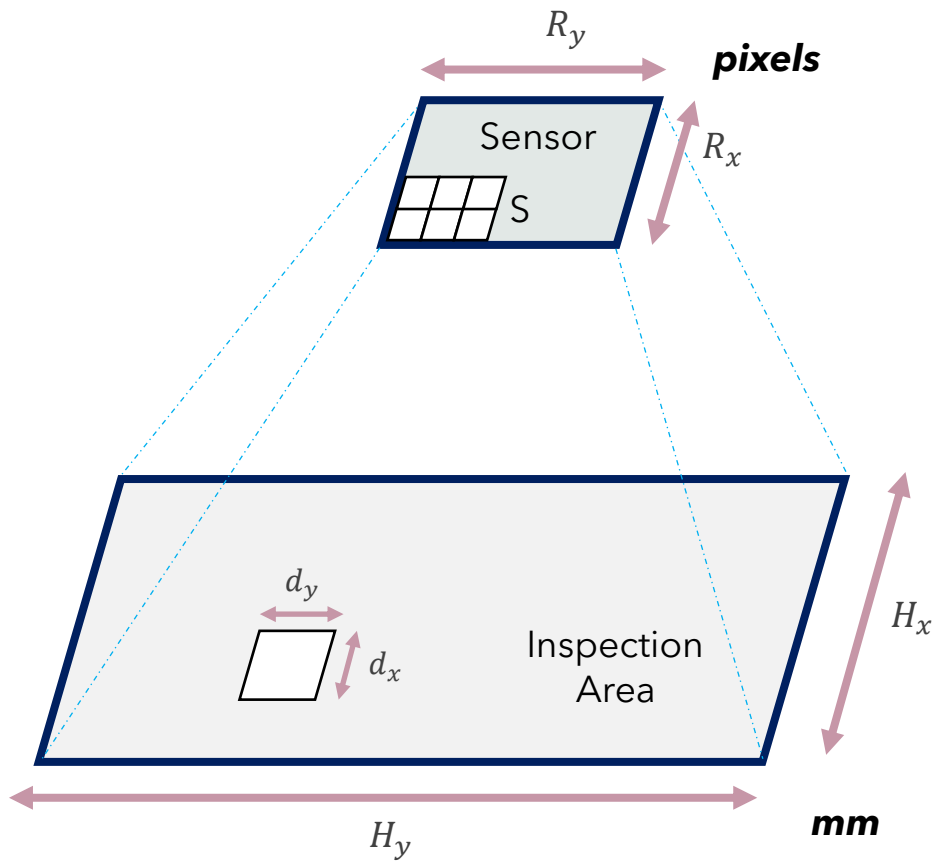
Spatial resolution / P

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)*

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)

V : motion speed (mm/s)

Spatial resolution / P

Distance observed by a single pixel in a given direction

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

Displacement
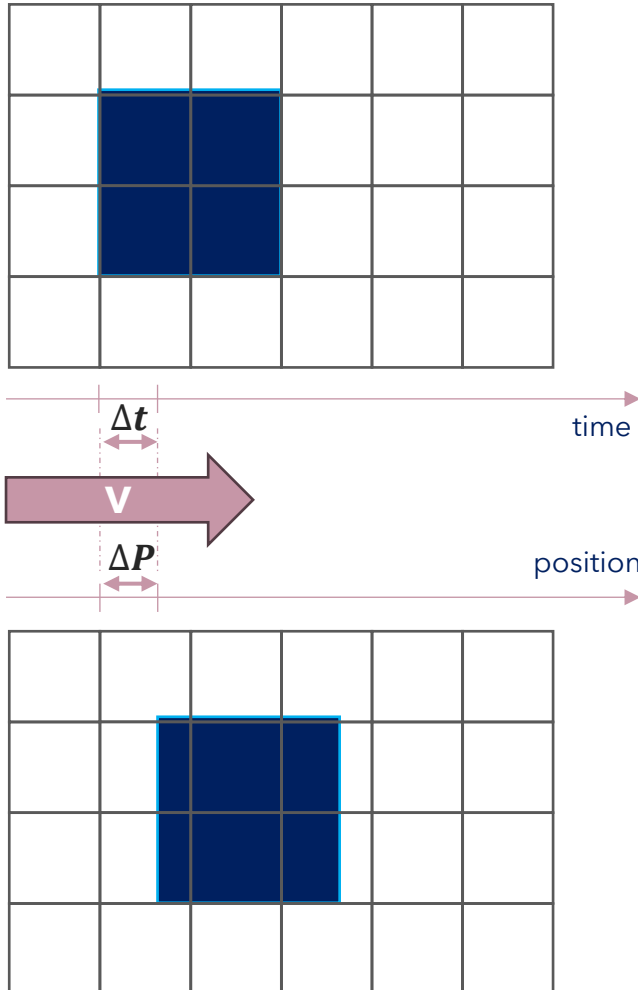
$P \times \Delta P$ (mm) ➔ Δt (s)

Motion blur perception threshold *to obtain a sharp image* is between

1/2 and 1/5 of a pixel

Time

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

Δt

V

ΔP

time

position

Bayer filter and image reconstruction
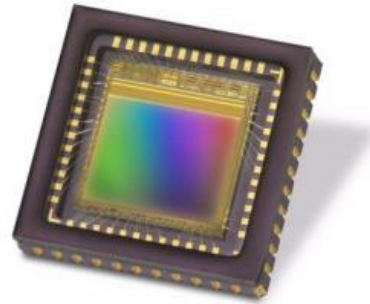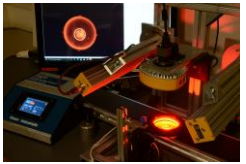
e2v sensor EV76C560ACT

Interpolation