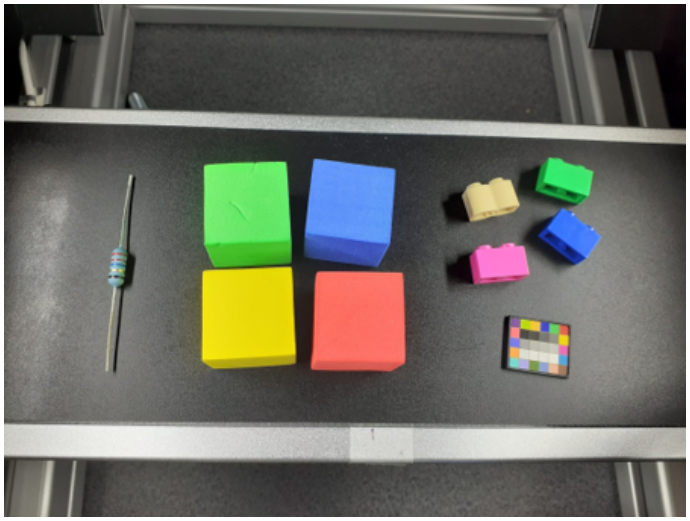
Institut d'Optique Graduate School
INTERFAÇAGE NUMÉRIQUE

Travaux Pratiques

Semestre 5

Vision Industrielle

Ressources

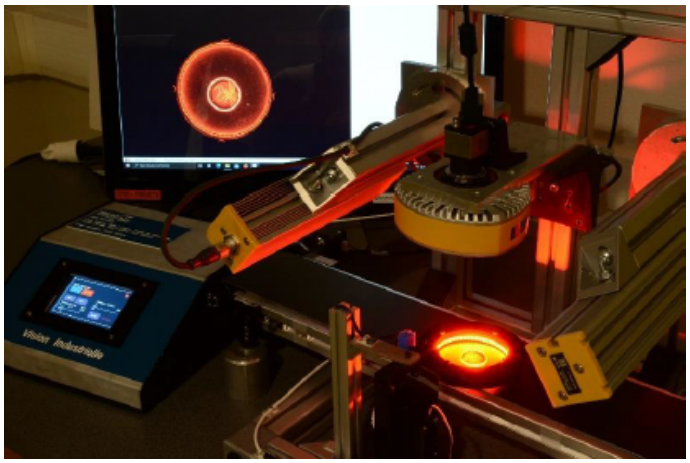


Ce sujet est disponible au format électronique sur le site du LEnsE - https ://lense.institutoptique.fr/ dans la rubrique Année / Première Année / Opto-Electronique S5 / TP / Bloc Vision Industrielle.

L'image de la page de garde provient du projet DEPhI Vision Industrielle de 2026. Crédits : Joséphine BECHU, Justine GABRIEL et Paul CHENEAU (Promo 2027).

Vision Industrielle

La **vision industrielle** est une technologie qui permet à des machines d'**analyser automatiquement des scènes** pour **contrôler**, **guider** ou **inspecter** des objets sur des processus de production. Elle repose sur l'utilisation de **caméras**, d'**optique**, d'**éclairages** spécifiques (ou contraints), de **capteurs** et d'algorithmes de **traitement d'image**.



Elle a pour but de **prendre des décisions automatiques** (ou aider l'être humain dans sa prise de décision) vis-à-vis d'un (ou plusieurs) objet(s) dans une scène spécifique : détecter des défauts ou des irrégularités, compter ou trier..., en rejetant ou validant automatiquement des produits, tout en assurant une constance de la qualité et de la répétabilité des opérations.

Ressources

Ce bloc de travaux pratiques utilise un **banc de vision industrielle** avec une lampe de type Effi-Ring RGB, une caméra Basler et une interface développée en **Python** (*PyQt6*) et qui utilise des fonctionnalités de la bibliothèque **OpenCV**.

Les documentations de la caméra et de l'éclairage sont disponibles aux adresses suivantes :

— Basler **a2A 1920 - 160ucBAS** : https://docs.baslerweb.com/a2a1920-160ucbas#specifications
— **Effi-Ring** : https://www.effilux.com/fr/produits/annulaire/effi-ring

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Liste des ressources présentes dans ce document

— Camera BASLER a2A1920-uc/umBAS (Résumé)
— Source EFFI-Ring - Spectre et données / Version RGB
— Cubes de couleur - Réflectance
— Rappels sur les caméra CMOS
— Rappels sur le traitement d'images

Camera BASLER a2A1920-uc/umBAS

La documentation complète se trouve sur le site du fabriquant - Basler

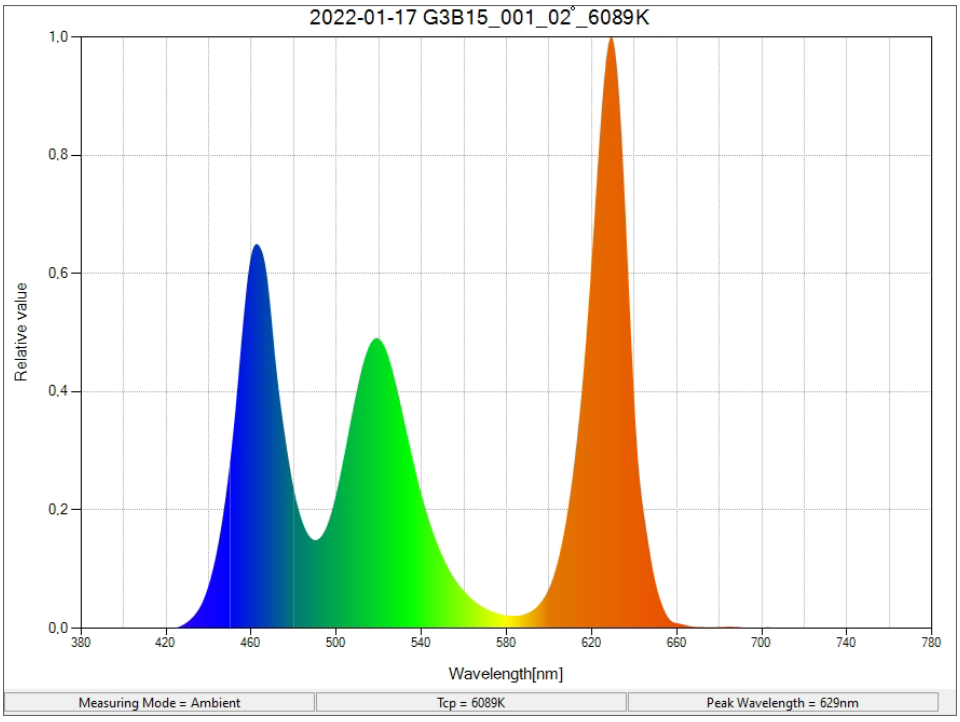
Marque Modèle	Basler a2A1920-160ucBAS
Résolution Taille pixel Profondeur	1920 px x 1200 px 3.45 x 3.45 μm^2 12 bits
Efficacité quantique Gain (1/K) Capacité de saturation Capacité de saturation	62.22 % 2.652 e-/DN 10492 e- 16862 p

Source EFFI-Ring - Spectre et données / Version RGB

La documentation complète se trouve sur le site du fabriquant - Effilux

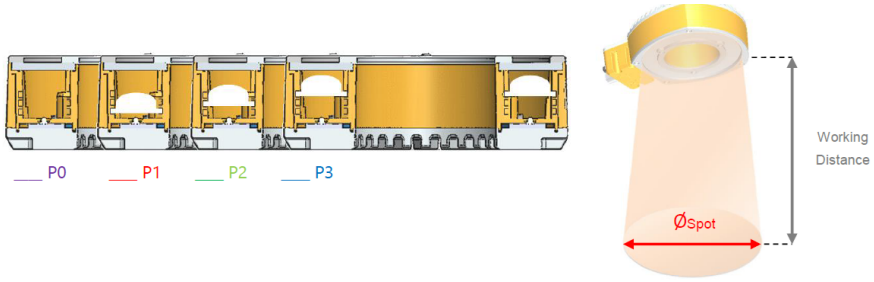
Spectre

Obtenu à l'aide d'un spectromètre



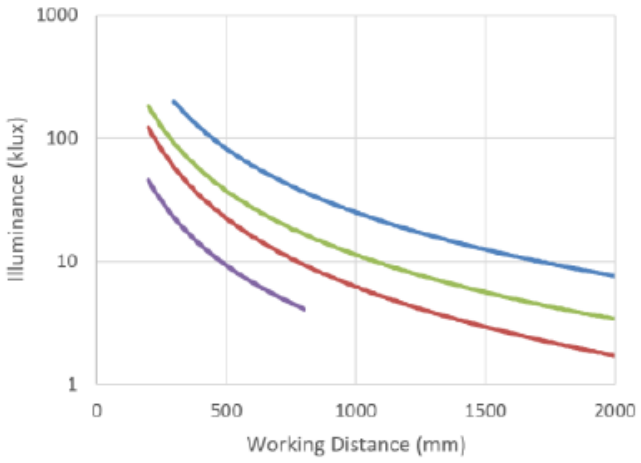
Taille du spot et éclairement en fonction de la distance de travail

Données provenant de la documentation technique.



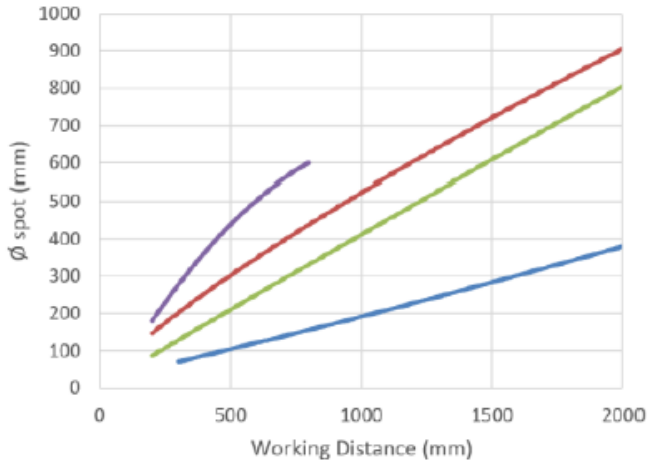
Illumination[1] vs. Working distance

Semi-Diffuse

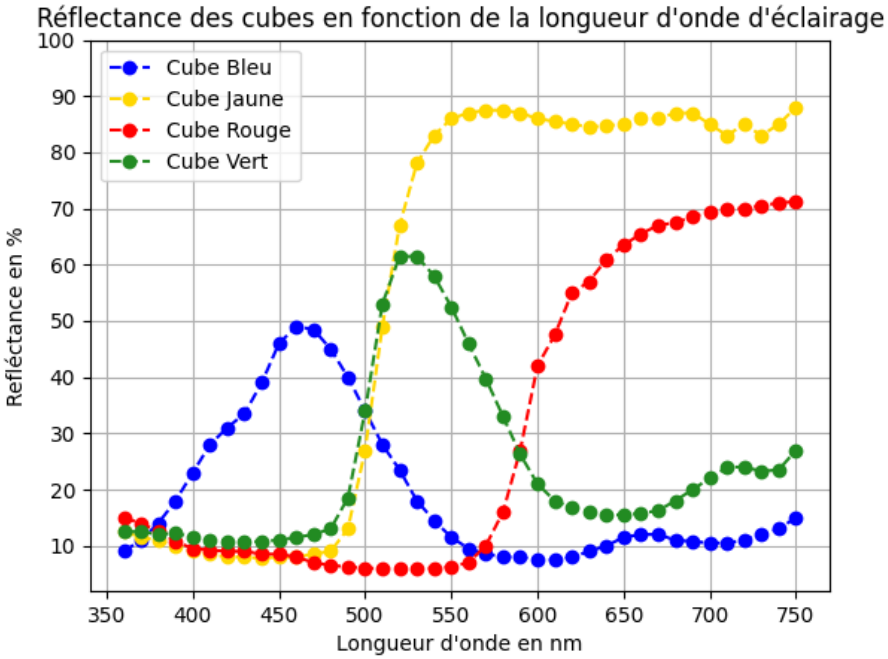


$Ø_{spot}$[3] vs. Working distance

Semi-Diffuse



Cubes de couleur - Réflectance



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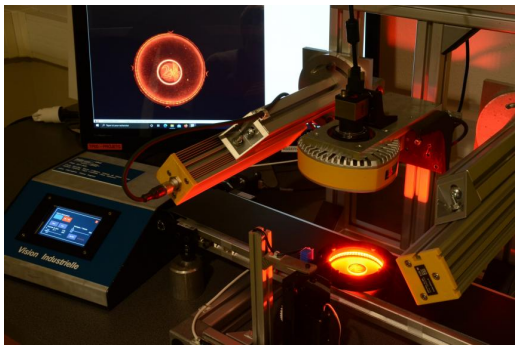
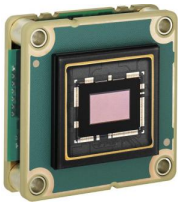
SC 19 – Machine Vision

Cameras and Interfaces

Julien VILLEMEJANE



IDS Sensor



Basler Sensor / Mouser

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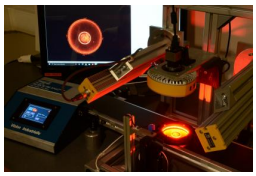
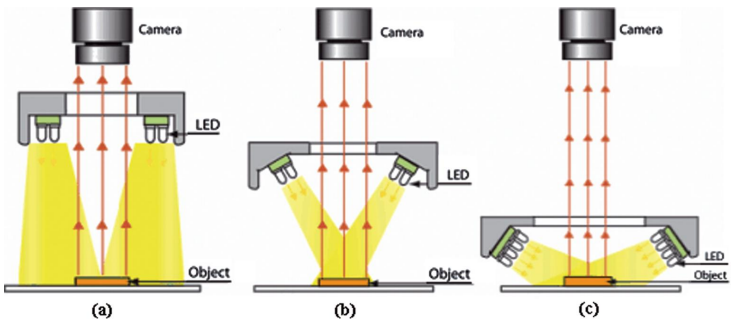


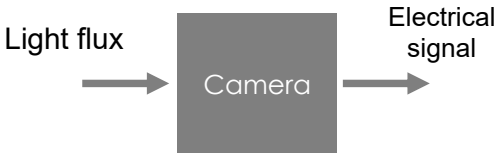
SC19 – Cameras and Interfaces

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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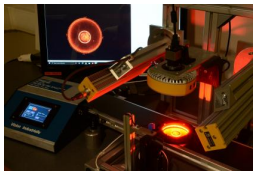


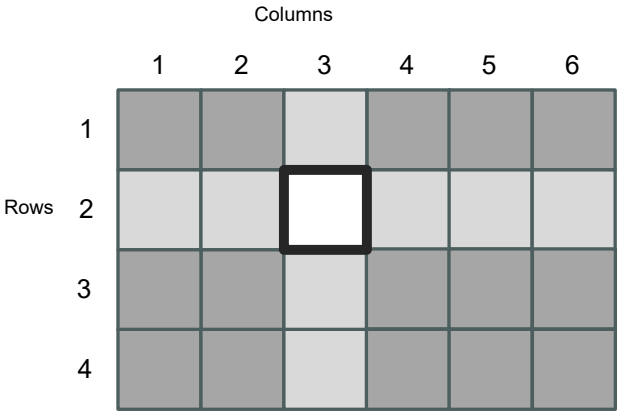
SC19 – Cameras and Interfaces

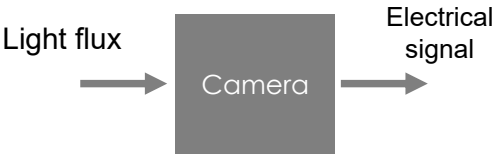
Camera / Array of small sensors

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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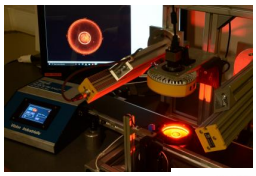
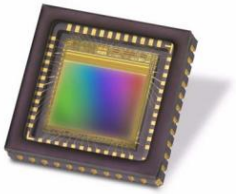
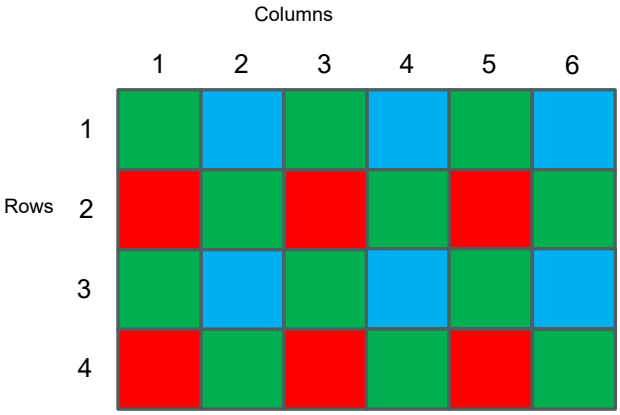


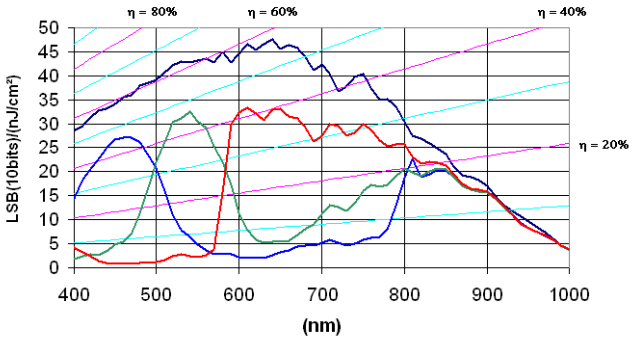
SC19 – Cameras and Interfaces

Camera / Bayer filter for color sensors



e2v sensor EV76C560ACT





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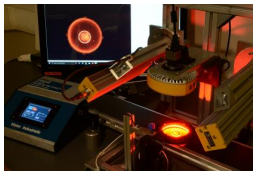
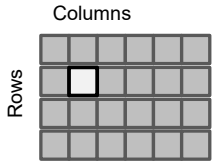


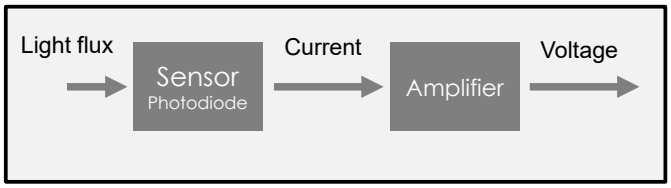
SC19 – Cameras and Interfaces

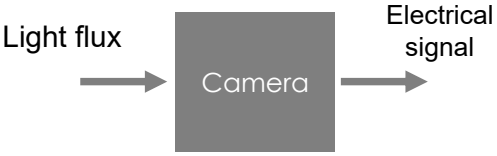
Camera / Inside a pixel

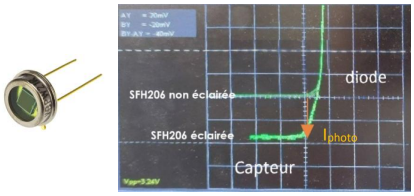


Camera

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







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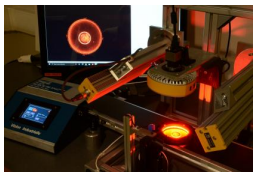
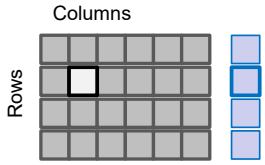


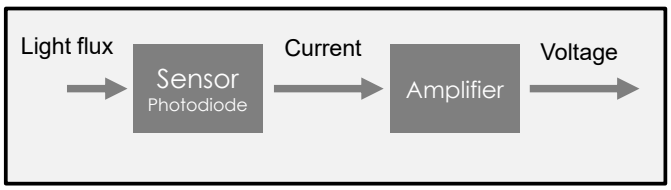
SC19 – Cameras and Interfaces

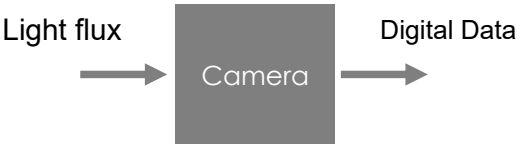
Camera / From analog to digital signal

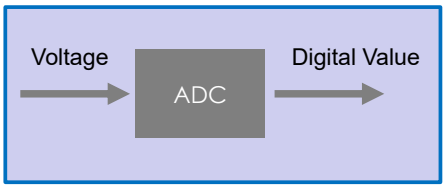


Digital Camera

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







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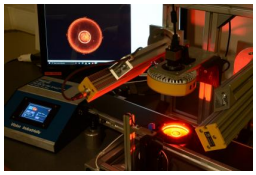
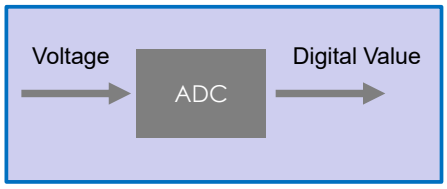
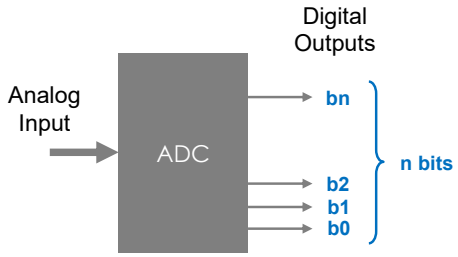


SC19 – Cameras and Interfaces

How an Analog to Digital Converter works ?



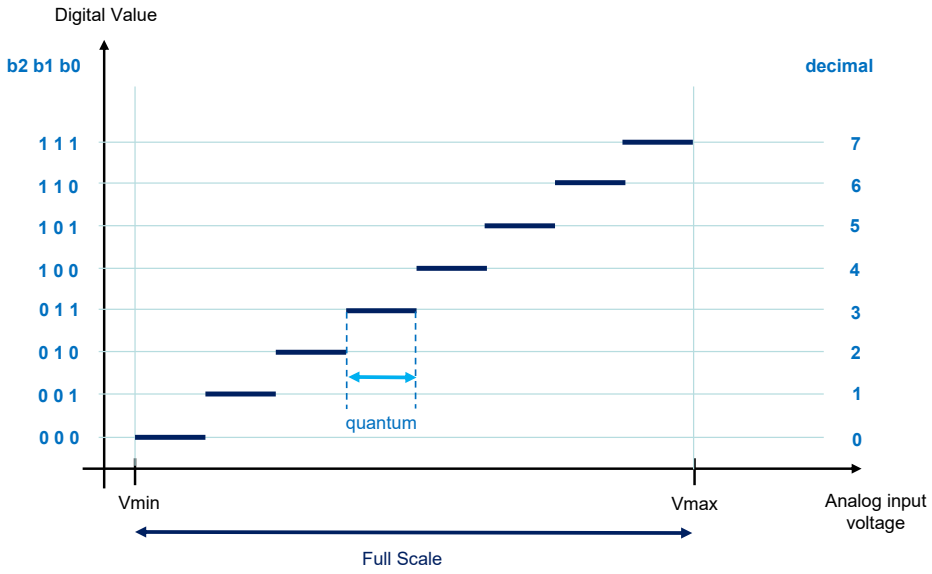


Each bit can have one of two values: **0** or **1**.

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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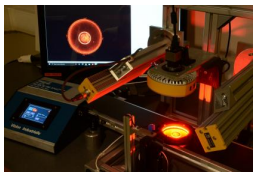
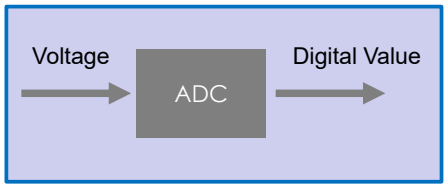
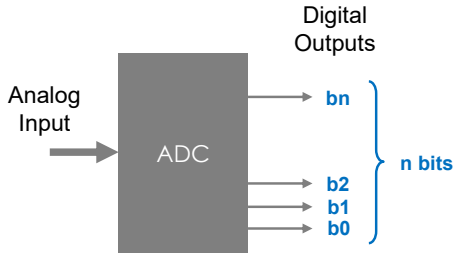


SC19 – Cameras and Interfaces

Sampling and quantization of an image

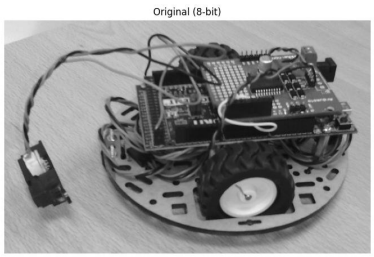
Quantization

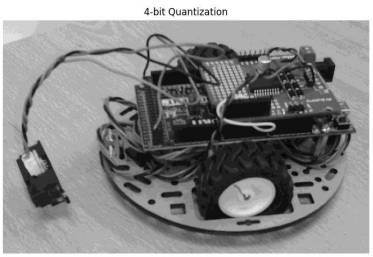


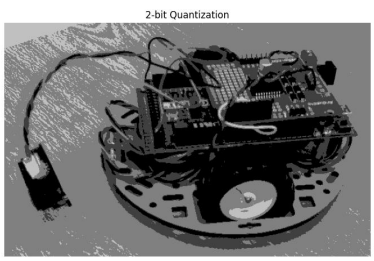


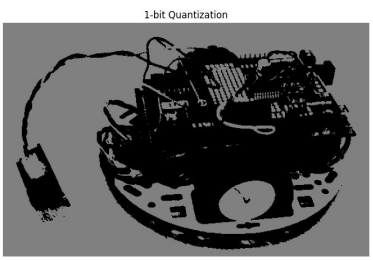
Each bit can have one of two values: **0** or **1**.

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









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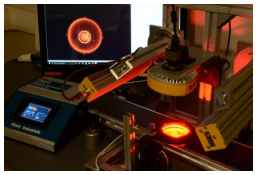
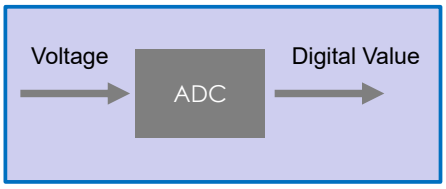


SC19 – Cameras and Interfaces

Sampling and quantization of an image



Sampling

Barcode to decode

Area of sampling

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

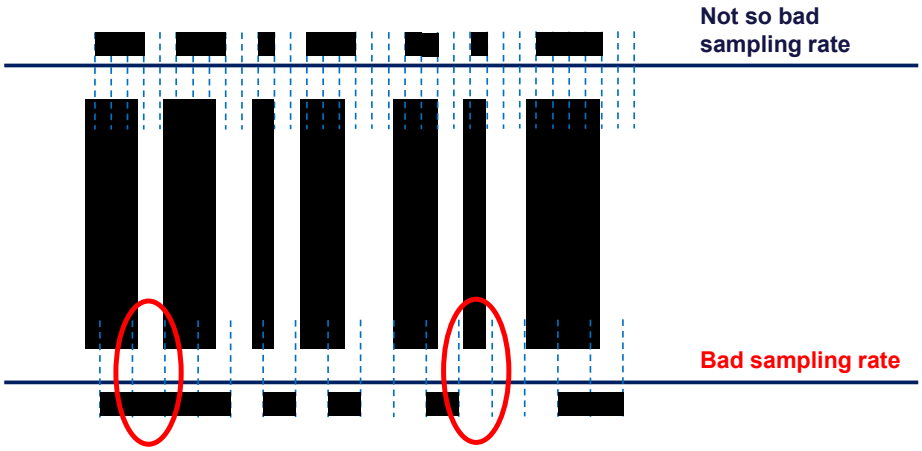
LEnsE 2024

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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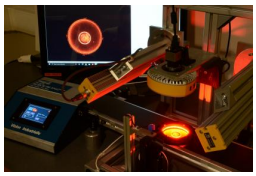
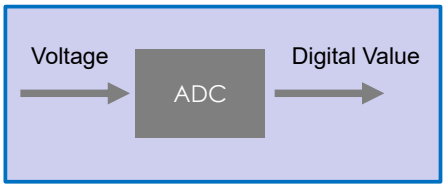
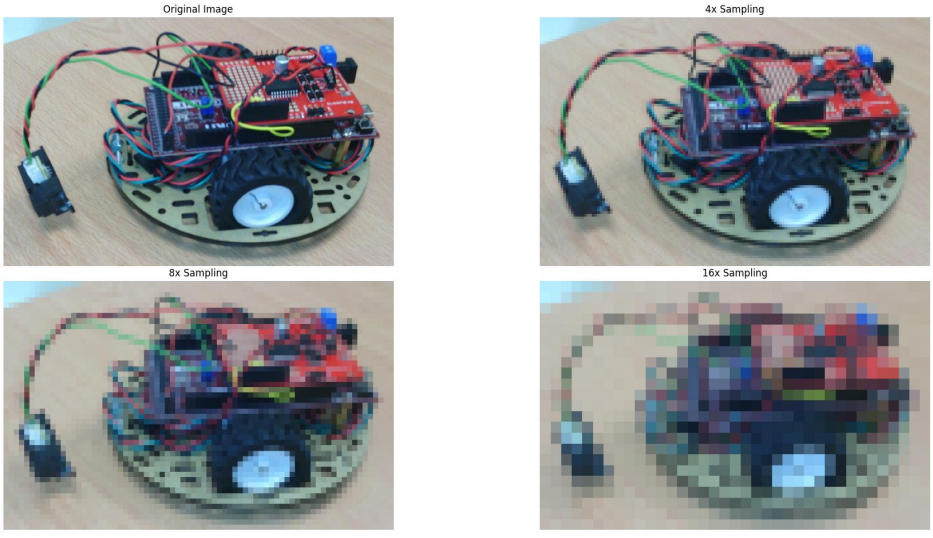


SC19 – Cameras and Interfaces

Sampling and quantization of an image



Sampling



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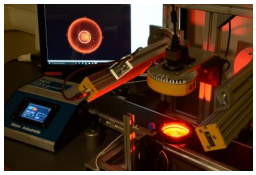
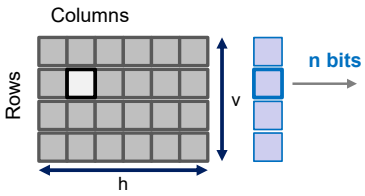


SC19 – Cameras and Interfaces

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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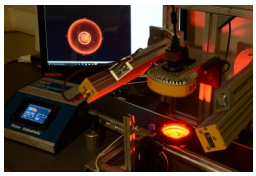

SC19 – Cameras and Interfaces

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)

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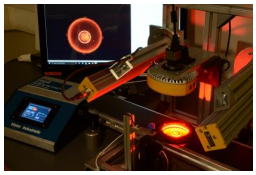
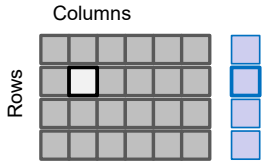
Formation Continue



SC19 – Cameras and Interfaces

Black level : an offset to compensate electronic defaults

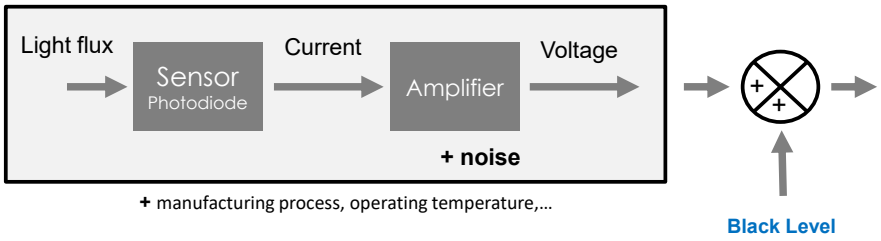


Dark Current

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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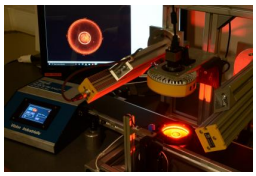
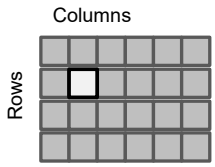
Formation Continue



SC19 – Cameras and Interfaces

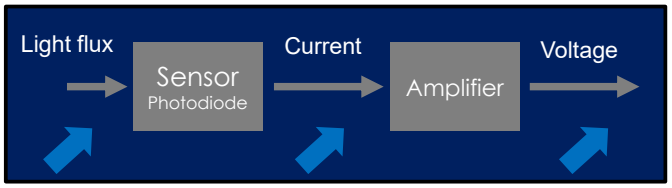
Exposure Time

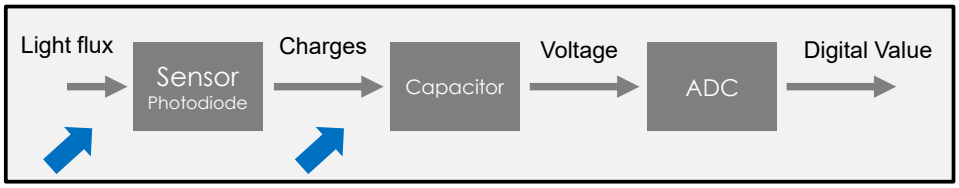


Exposure Time

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

This parameter determines the amount of light collected.





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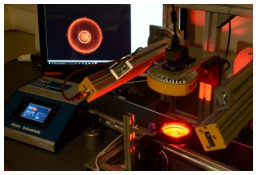
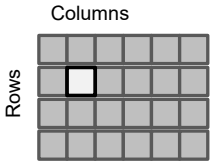
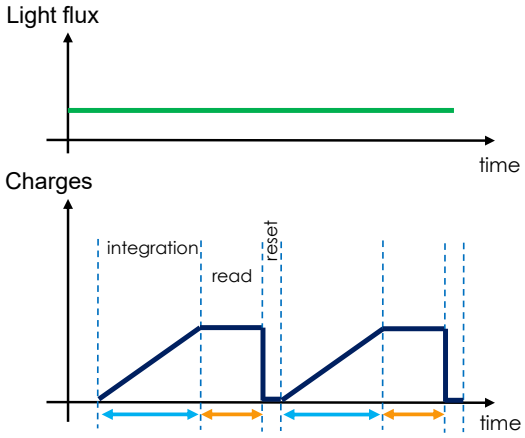
Formation Continue



SC19 – Cameras and Interfaces

Exposure Time



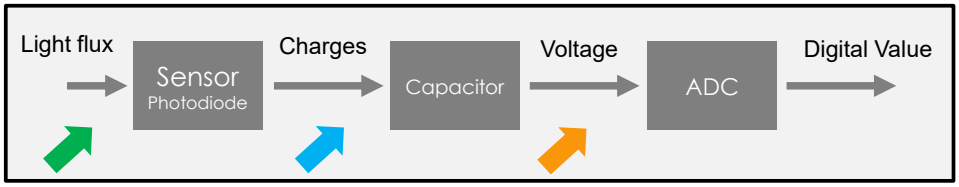


Exposure Time

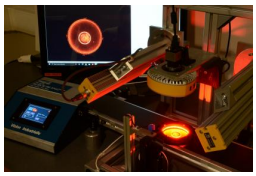
Duration for which the **camera's sensor is exposed to light**, when capturing an image.

This parameter determines the amount of light collected.

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

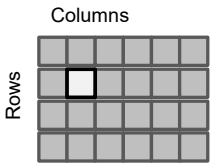


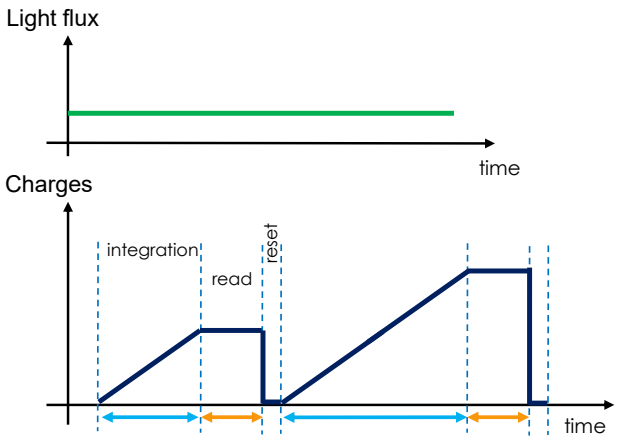
INSTITUT d'OPTIQUE GRADUATE SCHOOL | Continuing Education
Formation Continue



SC19 – Cameras and Interfaces

Exposure Time





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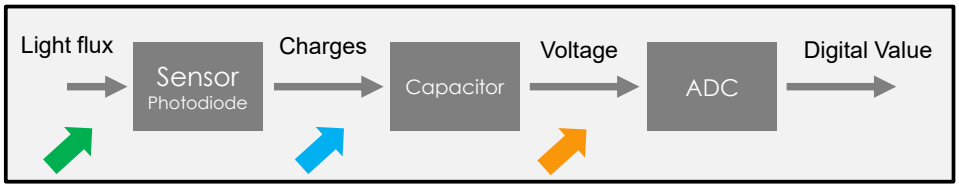

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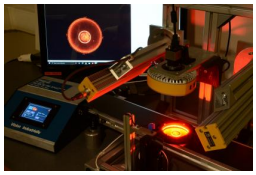
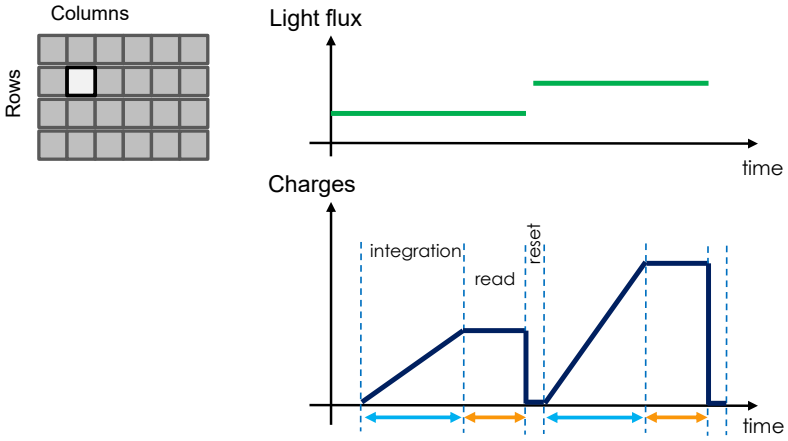


SC19 – Cameras and Interfaces

Exposure Time



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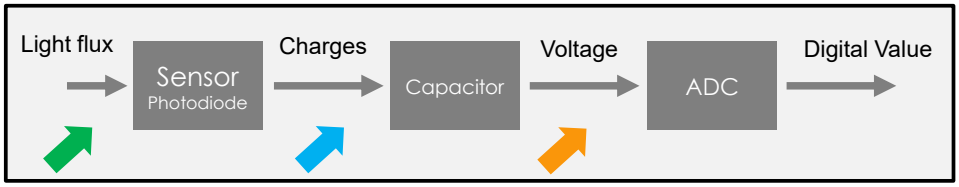

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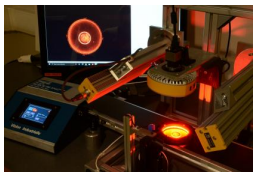
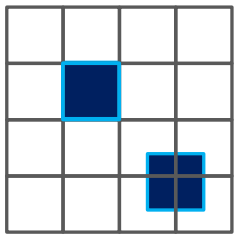


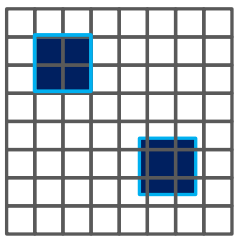
SC19 – Cameras and Interfaces

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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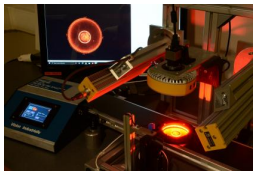
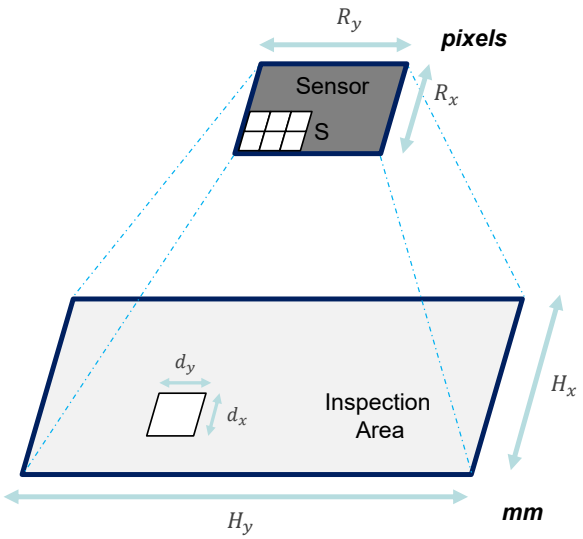


SC19 – Cameras and Interfaces

Resolution of the sensor



Spatial resolution / P

Distance observed by a single pixel in a given direction

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

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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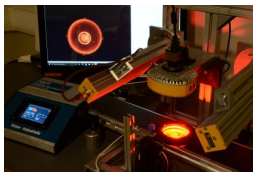
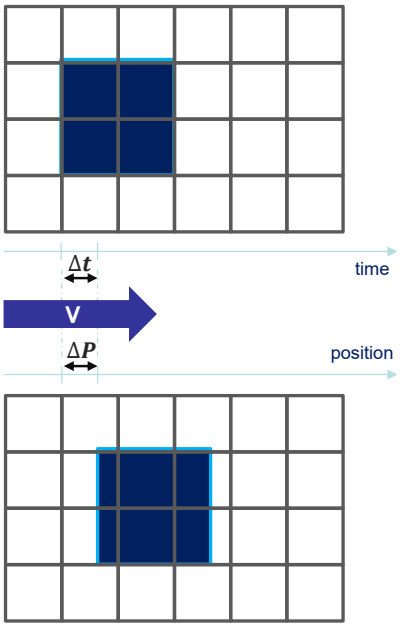


SC19 – Cameras and Interfaces

Motion, sharp image and maximum exposure time



V : motion speed (mm/s)

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

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

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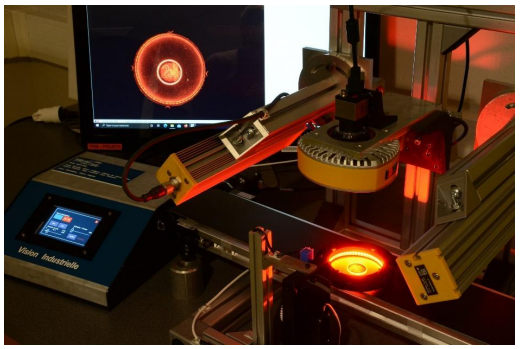
Traitement d'image

Pré-traitement / Segmentation / Classification



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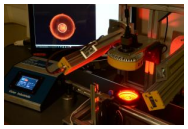

Traitement d'images

Objectif

Image brute 'RAW' / Caméra

- **Bruitée**
- Mauvais contraste
- Eclairage non uniforme
- …

Image souhaitée / Contours bien définis

- Zones homogènes
- Transitions nettes

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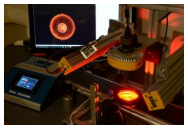
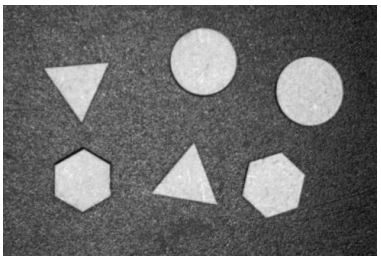
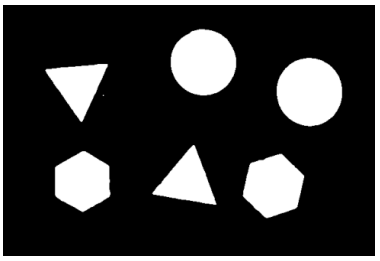


Traitement d'images





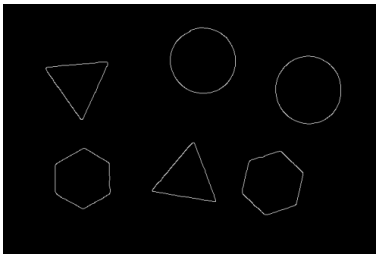


Image brute 'RAW' / Caméra

- **Bruitée**
- Mauvais contraste
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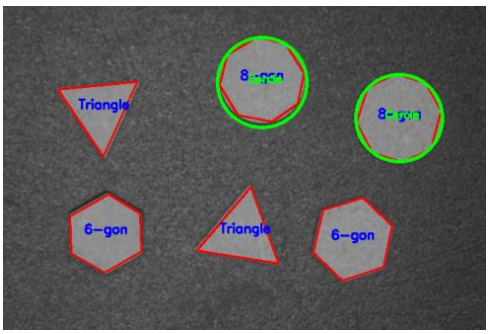
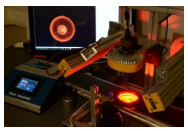


Image souhaitée / Contours bien définis

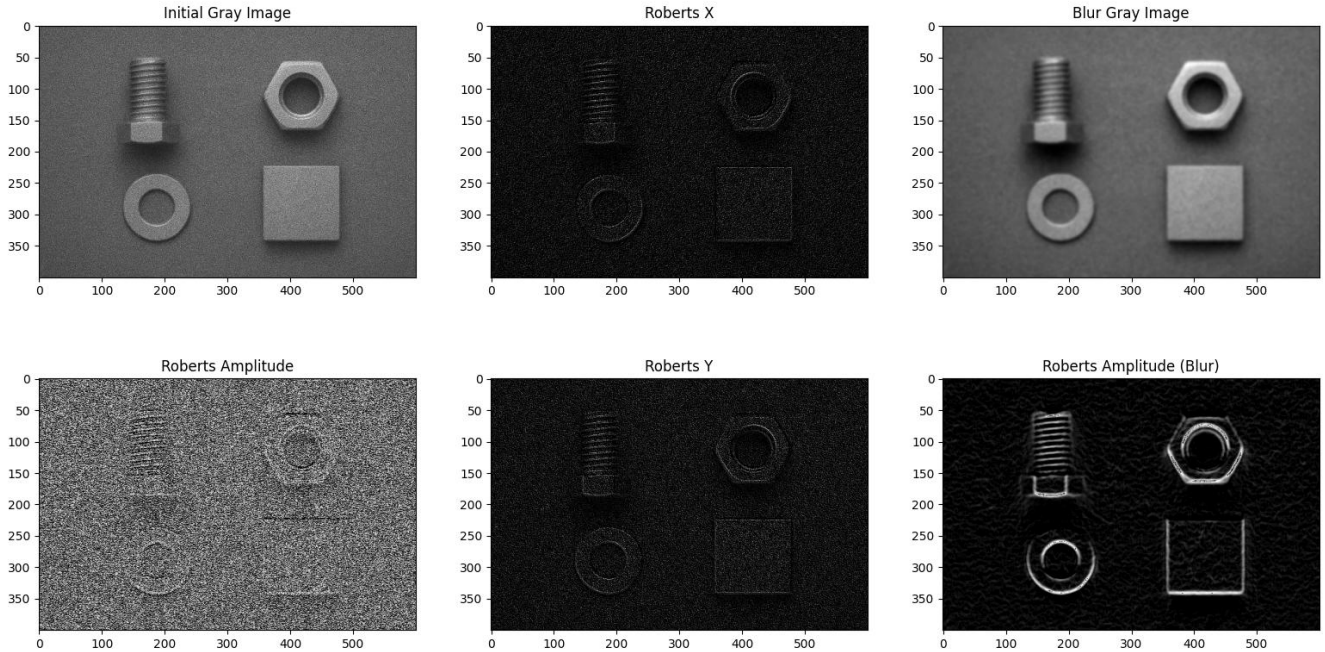
- Zones homogènes
- Transitions nettes

INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental



Traitement d'images

Exemple industriel



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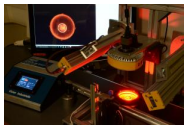

Traitement d'images

Objectif

Acquisition	Eclairage, caméra…	
Pré-Traitement	Filtrage / Réduction bruit Amélioration contraste Normalisation	Améliorer la clarté de l'image / réduire les informations indésirables Faire ressortir les caractéristiques d'intérêt Standardiser l'échelle ou l'intensité de l'image
Segmentation	Seuillage Détection de contours Sélection de régions d'intérêt	Isoler les objets de la région d'intérêt (ROI) Séparer les objets de l'arrière-plan Identifier les limites et les contours Se concentrer uniquement sur les parties pertinentes de l'image
Extraction d'informations	Formes géométriques Analyse de textures Zones uniformes	Extraire des données (taille, forme, position…) Reconnaitre des formes, des symboles ou des points d'intérêt
Classification	Détection d'objets Reconnaissance Classification	Identifier et nommer des objets Vérifier si les données mesurées sont en accord avec un cahier des charges Catégoriser des objets dans des groupes spécifiques
Décision	Tolérances, pièce valide/non valide, retour en temps réel…	

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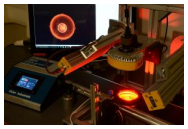


Traitement d'images

OpenCV

Open Source Computer Vision

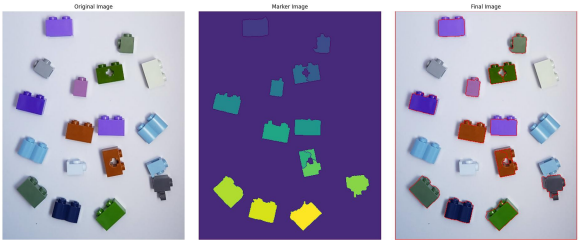
Une bibliothèque de **traitement d'images** et de **Machine learning**

Développés sur de multiple environnement, comme Python, C++, Java, and MATLAB

OpenCV

https://opencv.org

Traitement d'images	*Filtrage, detection de contours, transformations…*
Reconnaissance	*Détection d'objets dans des images et des vidéos*
Algorithmes Vidéo	*Suivi de mouvement, Reconstruction 3D…*
Machine Learning	*Classification d'images, Reconnaissance de formes*



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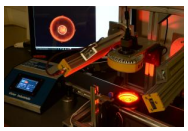


Traitement d'images

Images numériques

Image continue

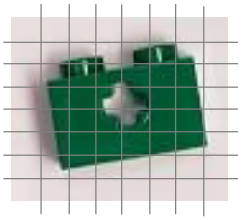
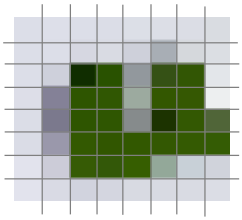
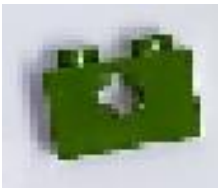


Image numérique : projection sur une matrice d'une image continue



8 x 8 grid

16 x 16 grid



32 x 32 grid

Image numérique

Représentation d'une **image sous forme numérique**

*Pour être **sauvegardée**, **traitée** et **affichée** par des ordinateurs ou des systems numériques.*

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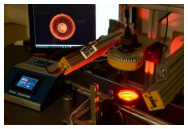
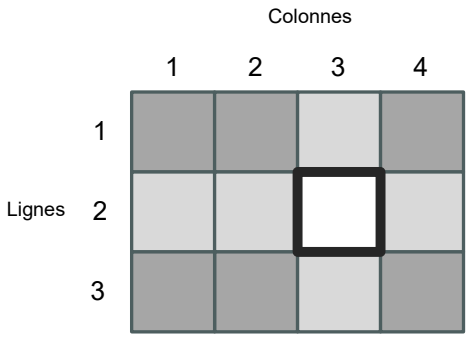


Traitement d'images

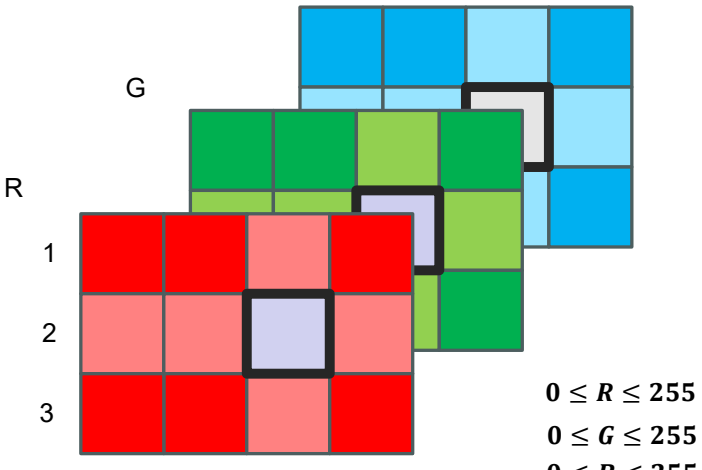
Images numériques / Gris ou RGB

Gris

Nb de pixels = **h** x **v**



Chaque pixel est converti sur **n bits**.



$0 \leq R \leq 255$

$0 \leq G \leq 255$

$0 \leq B \leq 255$

RGB : 3 canaux de 8 bits

R=200, G=100, G=50

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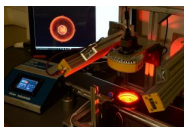


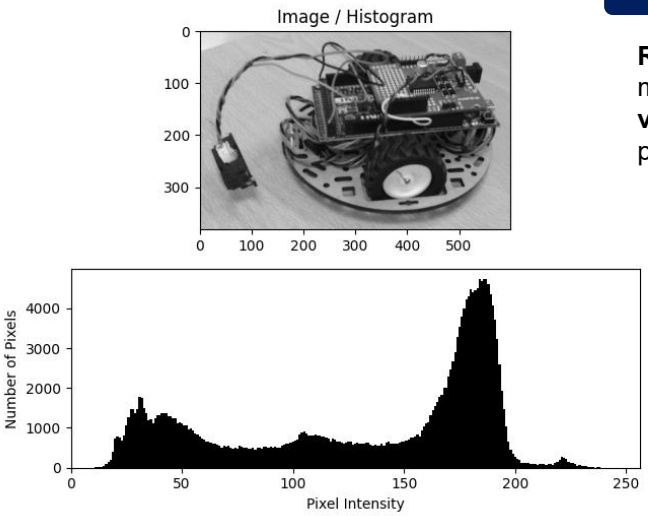
Traitement d'images

Filtrage par TF

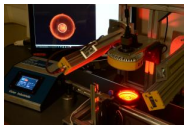
Acquisition

Histogramme

Représentation graphique montrant la **distribution des valeurs de niveaux de gris** des pixels de l'image



INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental

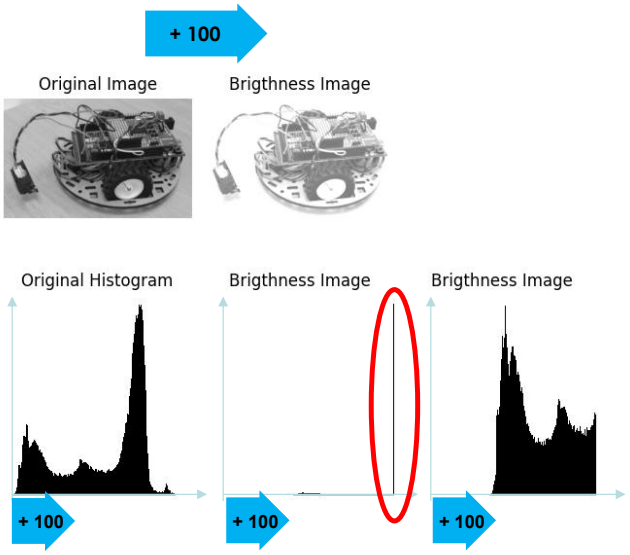


Traitement d'images

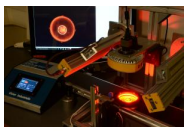
Amélioration de l'image

Acquisition

Pre Processing



INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental

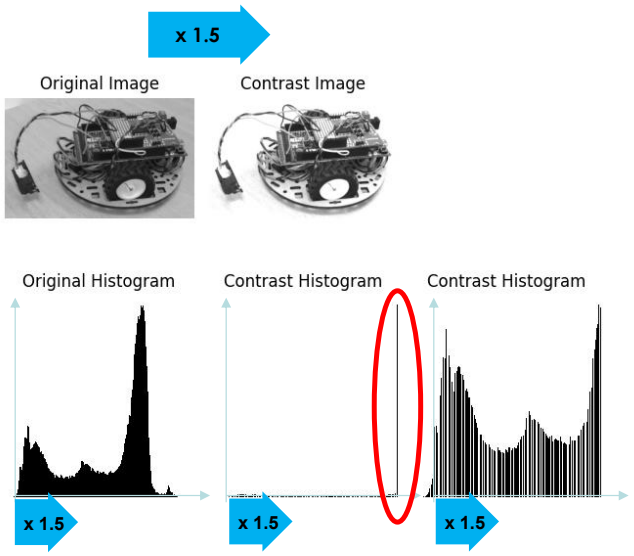


Traitement d'images

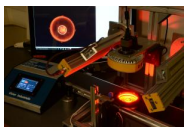
Amélioration de l'image

Acquisition

Pre Processing



INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental

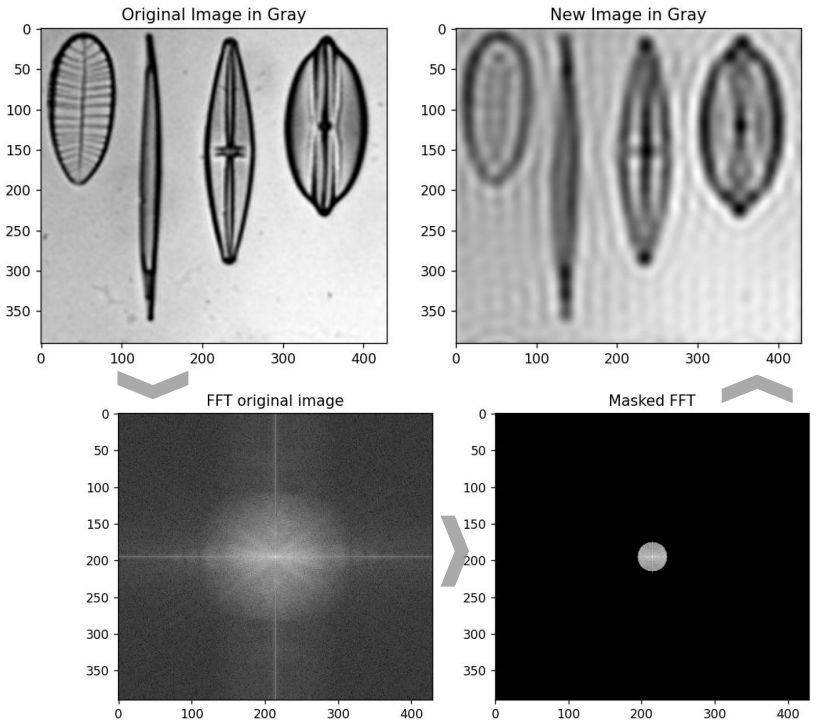


Traitement d'images

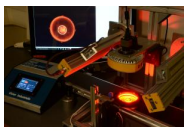
Filtrage par TF

Acquisition

Pre Processing



INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental



Traitement d'images

Filtrage / Convolution

Acquisition

Pre Processing

kernel

-1	0	-2
1	5	1
-2	0	-1

original image

5	8	4	2	3	1	5
9	5	1	8	7	6	2
5	7	1	5	6	8	7
5	8	2	8	4	3	3
5	6	6	7	2	5	1

5	8	4	2	3	1	5
9	5	1	8 x -1	7 x 0	6 x -2	2
5	7	1	5 x 1	6 x 5	8 x 1	7
5	8	2	8 x -2	4 x 0	3 x -1	3
5	6	6	7	2	5	1

R = -8 + 0 – 12 + 5 + 30 + 8 – 16 + 0 – 3
R = 4

filtered image

				4		

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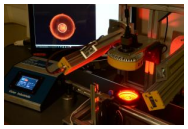


Traitement d'images

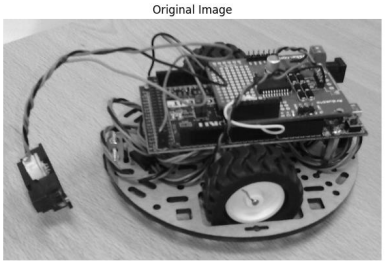
Filtrage / Convolution

Acquisition

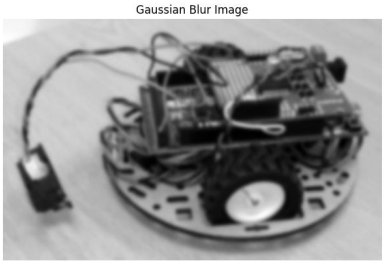
Pre Processing

Suppression de détails insignifiants

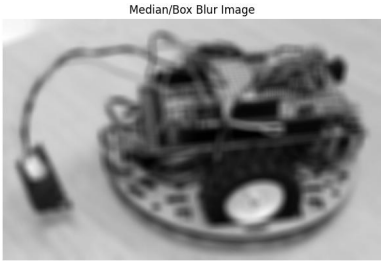
Original Image



Gaussian Blur Image



Median/Box Blur Image



1	4	7	4	1
4	16	26	16	4
7	26	41	26	7
4	16	26	16	4
1	4	7	4	1

Gaussian Kernel
(x 1/273)

Mean Kernel (x 1/(N*M))

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

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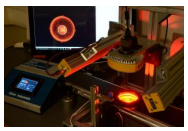
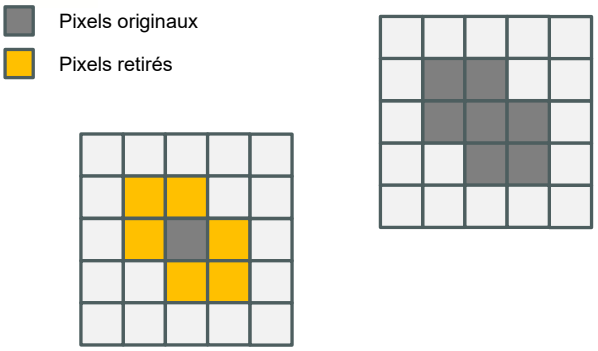


Traitement d'images

Erosion / Dilatation

Acquisition

Pre Processing



kernel

0	1	0
1	1	1
0	1	0

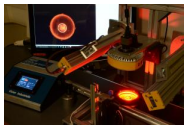
Erosion

Réduire le premier plan en retirant progressivement les pixels le long des contours des objets

Dilatation

Étendre le premier plan en ajoutant des pixels le long des contours des objets

INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental

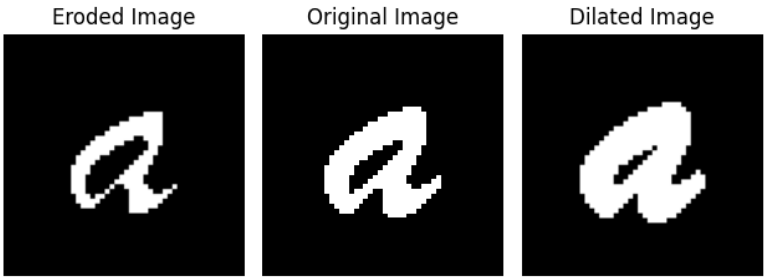


Traitement d'images

Erosion / Dilatation

Acquisition

Pre Processing



kernel

0	1	0
1	1	1
0	1	0

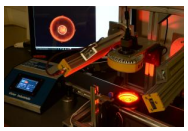
Erosion

Réduire le premier plan en retirant progressivement les pixels le long des contours des objets

Dilatation

Étendre le premier plan en ajoutant des pixels le long des contours des objets

INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental



Traitement d'images

Ouverture / Fermeture

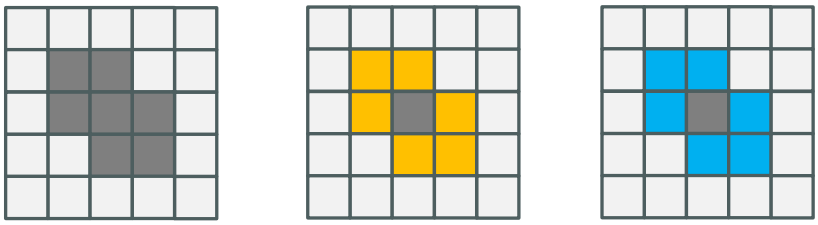
Acquisition

Pre Processing

Original pixels

Removed pixels

Added pixels



kernel

0	1	0
1	1	1
0	1	0

Ouverture

Erosion puis **Dilatation**

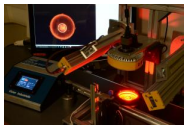
Retire des petits objets

Fermeture

Dilatation puis **Erosion**

Remplit des petites zones

INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental

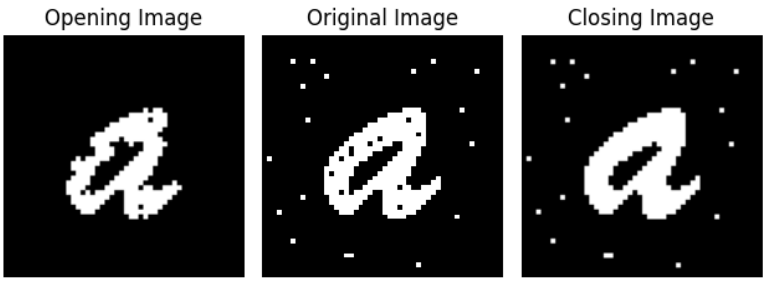


Traitement d'images

Ouverture / Fermeture

Acquisition

Pre Processing



kernel

0	1	0
1	1	1
0	1	0

Ouverture

Erosion puis Dilatation

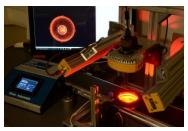
Retire des petits objets

Fermeture

Dilatation puis Erosion

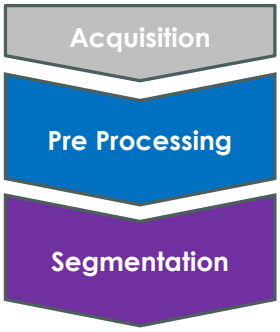
Remplit des petites zones

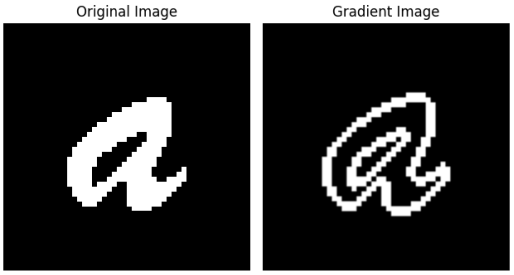
INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental



Traitement d'images

Gradient





kernel

0	1	0
1	1	1
0	1	0

Gradient

Difference entre une **dilatation** et une **érosion**

Classification des pixels : **scène** *(background)* ou **objets** *(foreground) ?*

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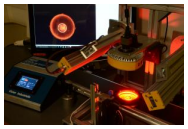
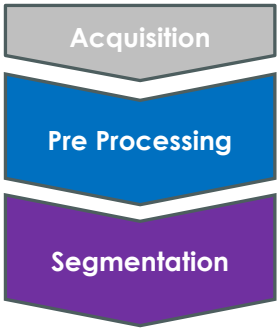
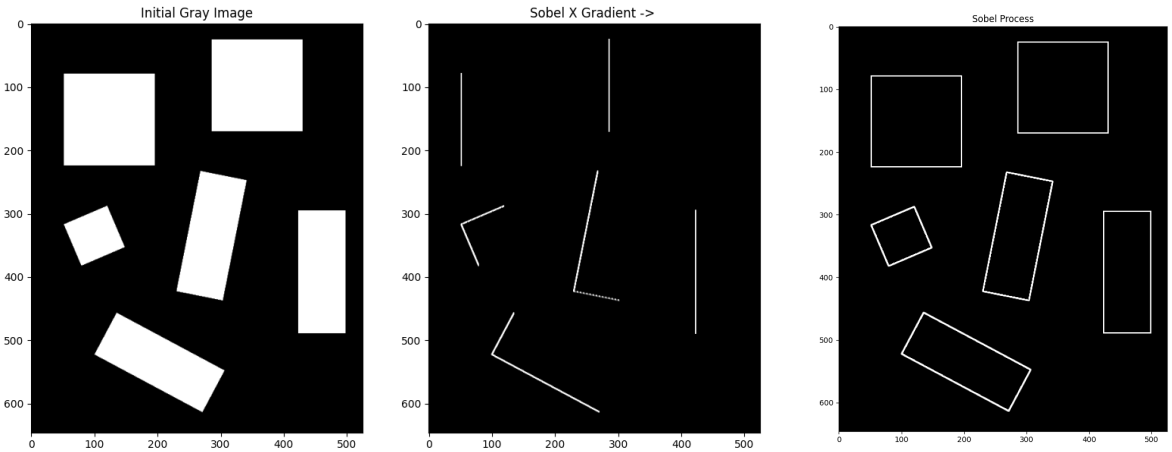


Traitement d'images

Opérateur de Sobel

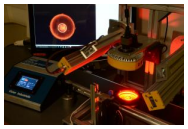




kernel

-1	0	1
-2	0	2
-1	0	1

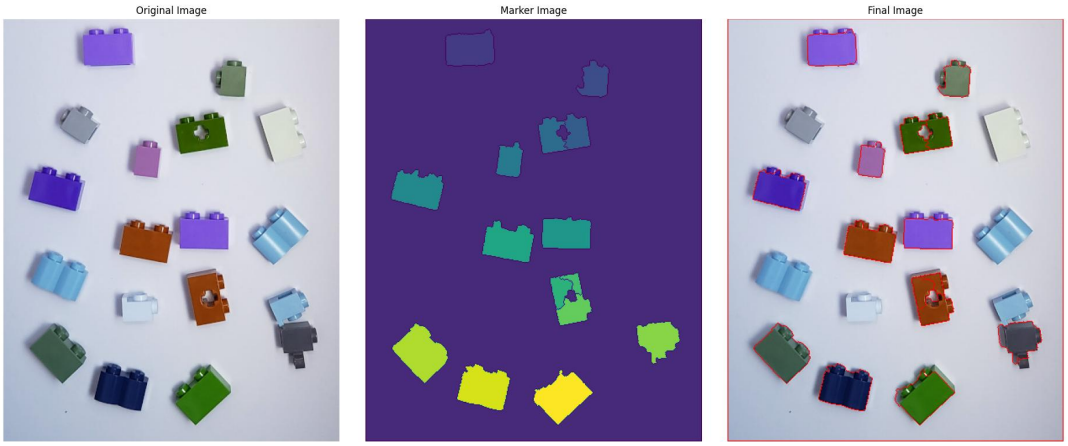
INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental



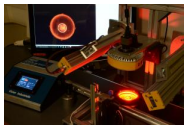
Traitement d'images

Méthode de Watershed

- Acquisition
- Pre Processing
- Segmentation
- Extraction d'informations
- Classification



INSTITUT d'OPTIQUE GRADUATE SCHOOL | LEnsE Laboratoire d'Enseignement Expérimental



Traitement d'images

Méthode de Watershed

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- Classification