Computer vision

Introduction

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Rules

40% project

10% test

50% final exam

Recommended readings

Počítačové Videnie
Detekcia a rozpoznávanie objektov

E. Šikudová, Z. Černeková, W. Benešová, Z. Haladová, and J. Kučerová
Praha: Wikina Praha, 2013, p. 397

Recommended readings

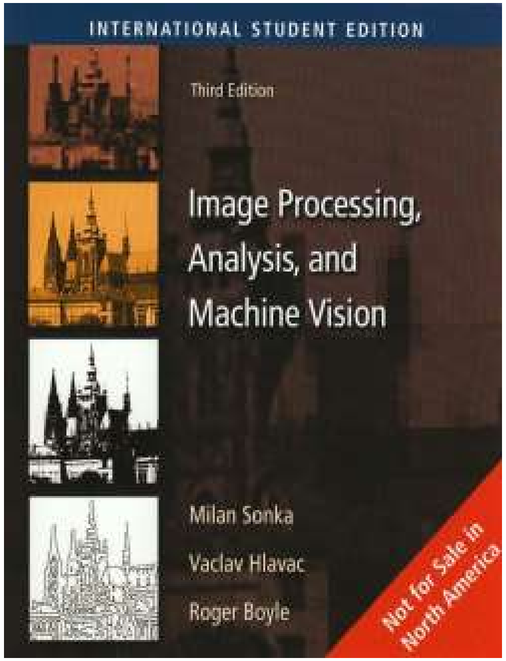
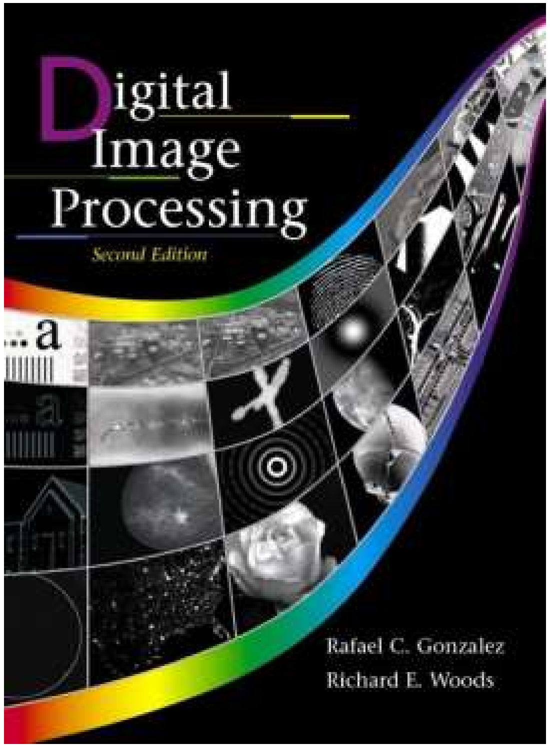


Image Processing, Analysis and Machine Vision

Milan Šonka, Václav Hlaváč, Roger Boyle

http://www.icaen.uiowa.edu/~dip/LECTURE/lecture.html

Recommended readings



Digital Image Processing
Rafael C. Gonzalez, University of Tennessee
Richard E. Woods, MedData Interactive

Publisher: Prentice Hall

www.prenhall.com/gonzalezwoods

Scope

What is „Computer vision“?

Application examples

Visual data acquisition

What is „Computer vision“?

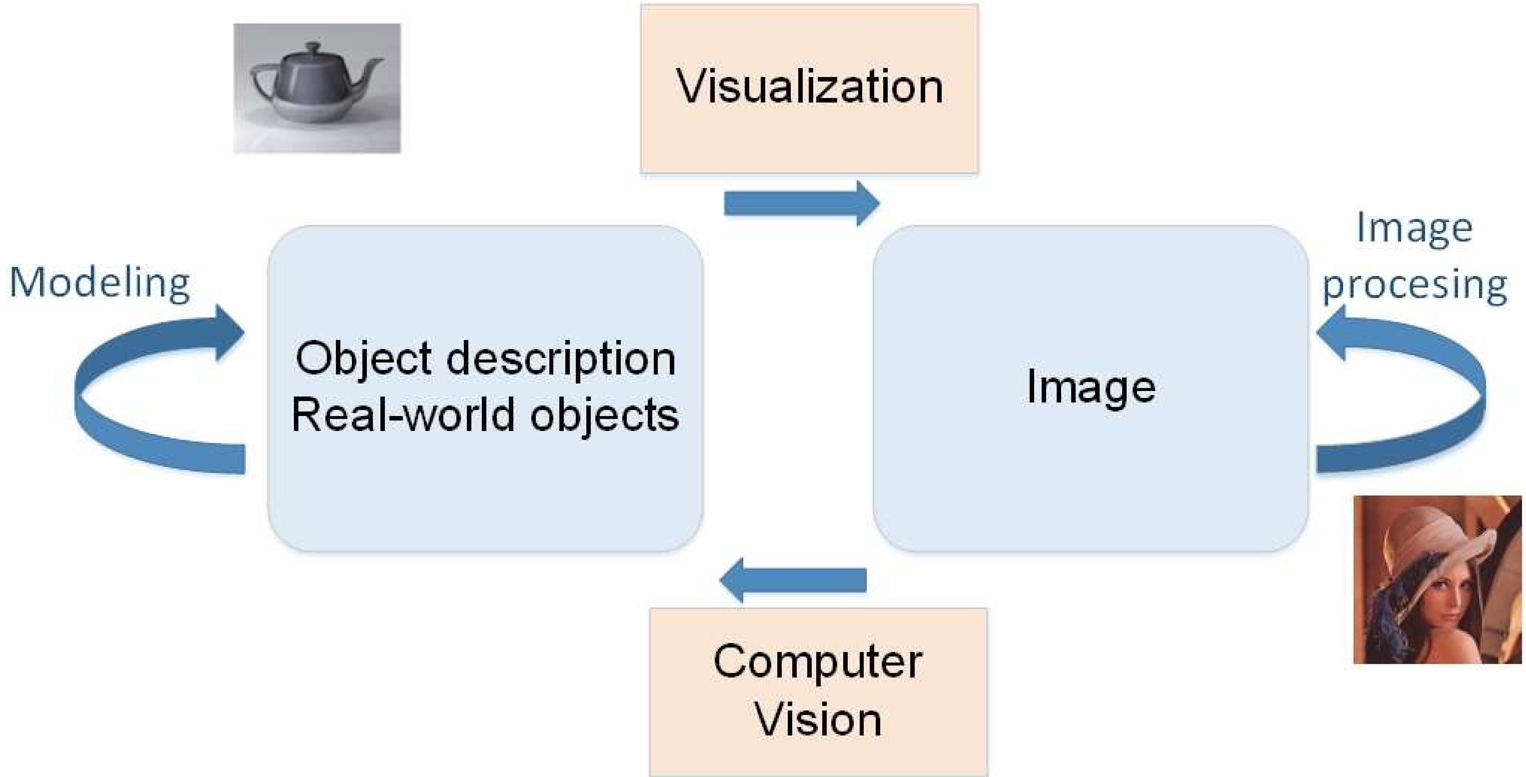
Image processing
Image understanding
Computer vision
Machine vision
Machine perception

What is „Computer vision“?

Computer vision is concerned with the automatic extraction, analysis and understanding of useful information from a single image or a sequence of images or other visual data.

It involves the development of a theoretical and algorithmic basis to achieve automatic visual understanding.

What is „Computer vision“?



Computer graphics vs. Computer vision

Image processing

Low level operations

- Image preprocessing
- Noise reduction
- Contrast enhancement
- Edge detection
- Morphological image processing
- Image sharpening
- Colour image processing
- Transforms (Fourier, Cosine, Wavelet)
- Image compression

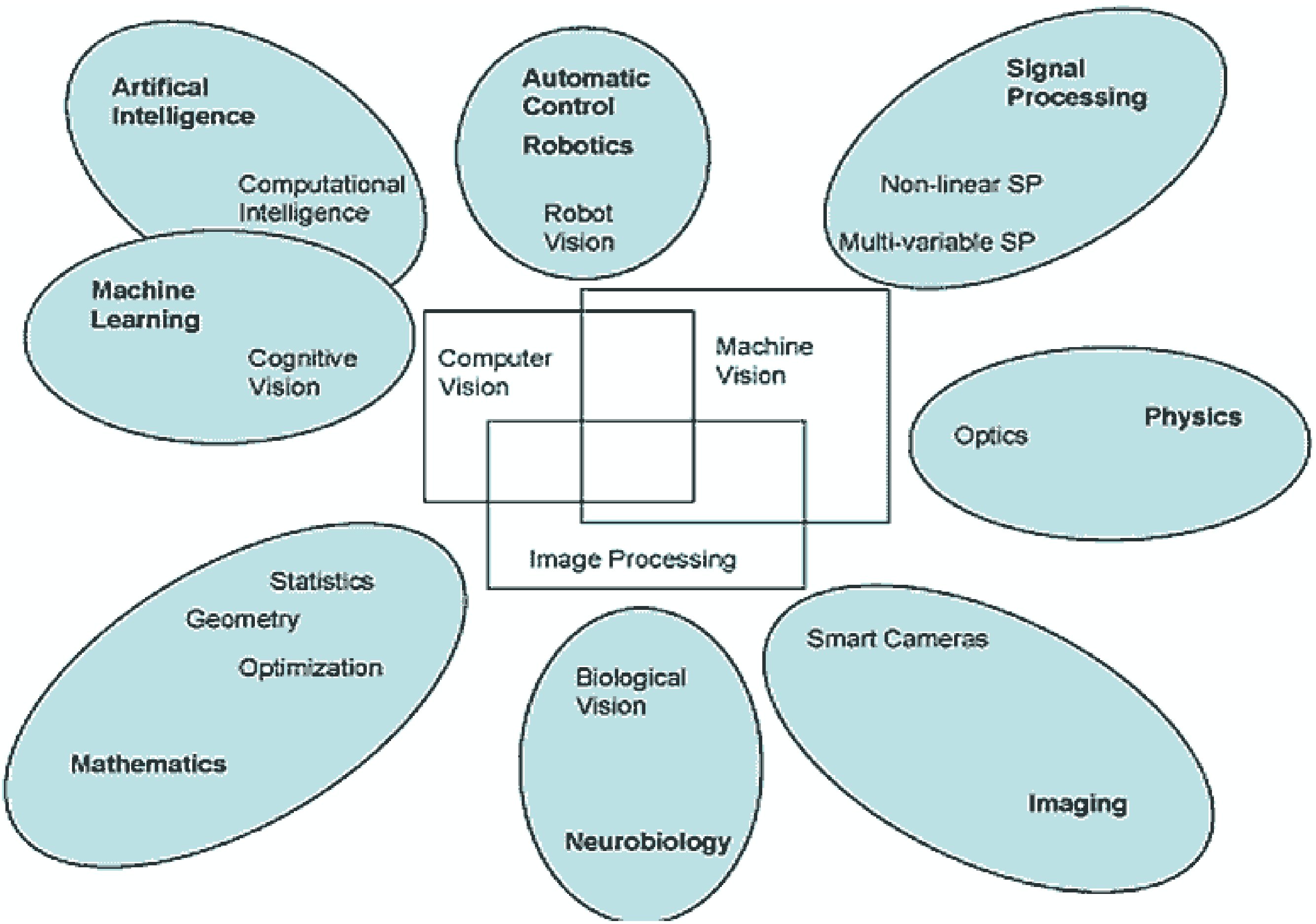
A low level process is characterized by the fact that both its inputs and outputs are images

Image processing -> Computer vision

Main topics of computer vision

- Segmentation
- Object detection
- Object recognition
- Scene analysis
- Pattern matching
- Object tracking
- Motion detection

Computer vision, Machine vision, Image processing & Related topics



Application examples

Applications

The applications of computer vision are numerous and include:

agriculture
augmented reality
autonomous vehicles
biometrics
character recognition
forensics
industrial quality inspection
face recognition
gesture analysis
geoscience

human-computer interaction
image restoration
medical imaging
environmental applications
process control
remote sensing
robotics
security
transportation
traffic applications

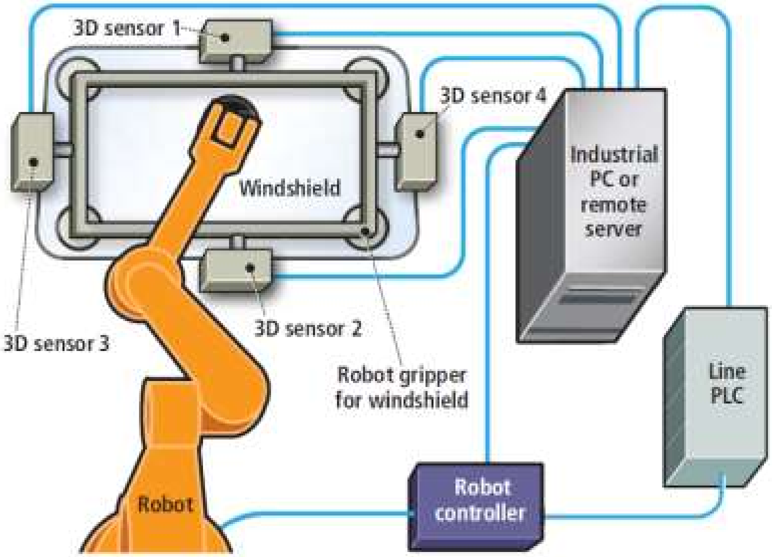
Industrial quality inspection

Process control

- Quality inspection
- Shape (2D/3D measurement)
- Position
- Surface
- OCR
- Measurement

Industrial quality inspection - examples

3D vision system guides robotic windshield placement



http://www.vision-systems.com/index.html

Industrial quality inspection - examples

3D vision system

Defects in specular surfaces

Phase measurement technique detects defects in specular surfaces

The human eye is certainly capable of identifying even the smallest topographical changes on the surfaces of objects; however, the nature of their surfaces often requires a particular automated imaging system for detailed analysis. A number of different methods have been used to measure the surface of diffusely reflecting objects, including structured-light projection, fringe pattern projection and stereo vision techniques.

However, when the surfaces of objects such as automotive body panels and optical components are specularly reflective, such techniques will not prove as effective. While alternative techniques such as white light interferometry can be used to assess surface defects, they are often limited by their small field of view.

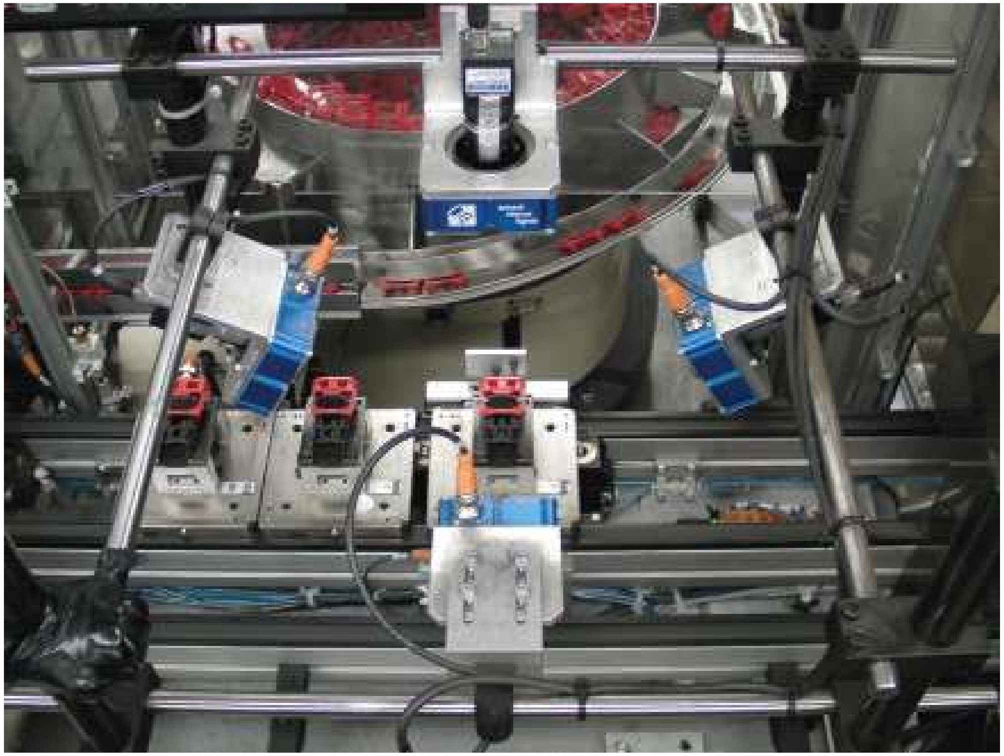
Now, Stefan Werling and his colleagues at the Fraunhofer Institute of Optronics (www.iosb.fraunhofer.de) have developed a technique known as phase measurement deflectometry (PMD) to overcome these limitations.

Specular objects reflect light in a single direction, so incoming light must be provided from many directions to ensure that some light is reflected into the camera system. Because of *Phase measurement continued on page 10*

FIGURE 1. At Fraunhofer IOSB, Stefan Werling and his colleagues have developed a system based on phase measurement deflectometry (PMD) to measure specularly reflective parts such as painted automotive panels.

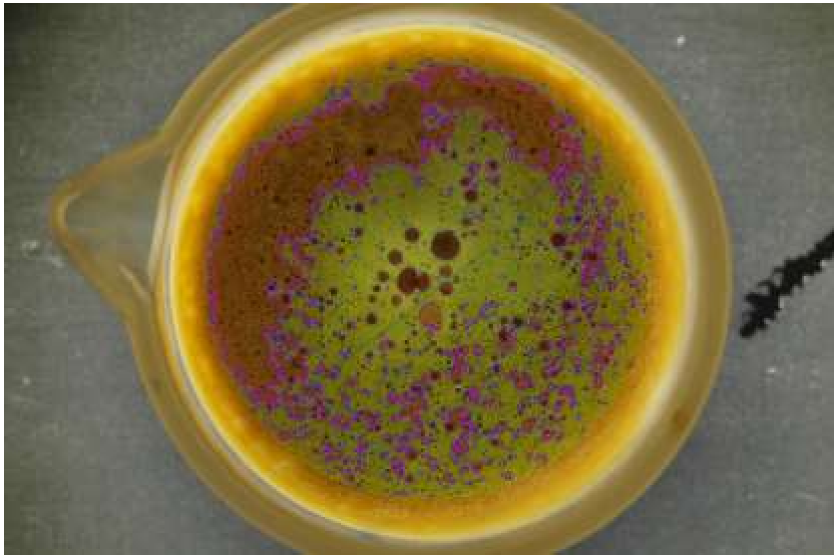
Industrial quality inspection - examples

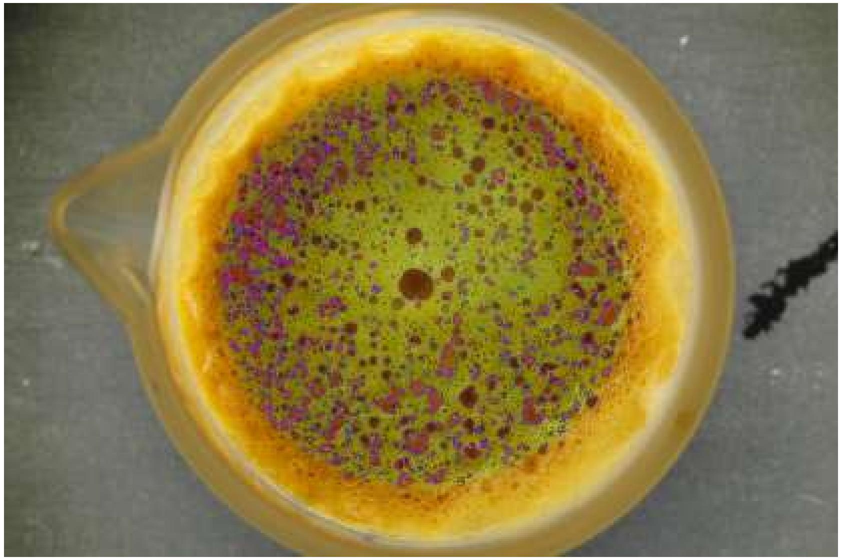
A four-camera vision system helps an automotive safety component manufacturer achieve 100% inline inspection of safety belt buckle assemblies.

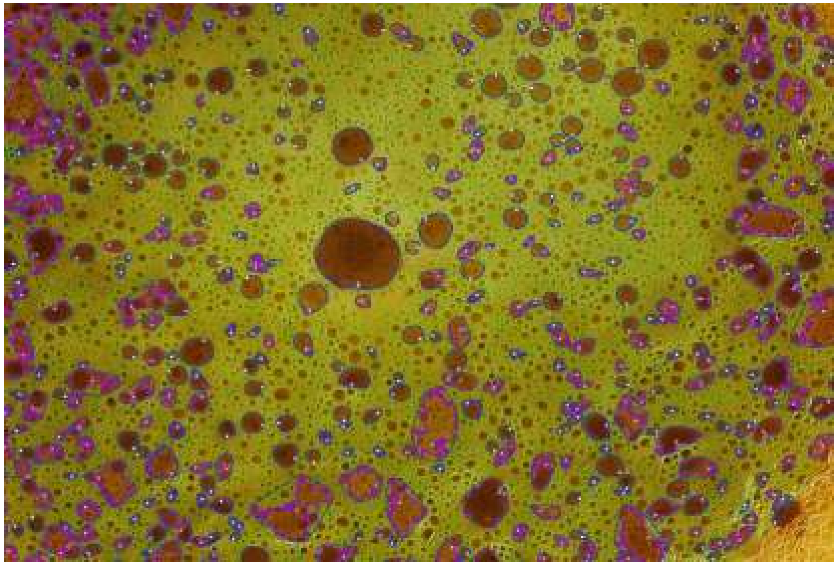


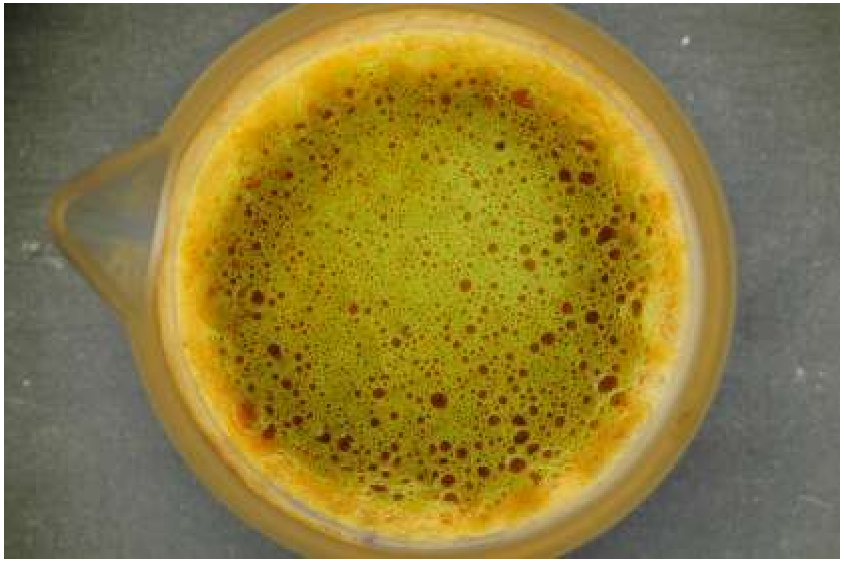
Industrial quality inspection - examples

Industrial quality inspection - examples

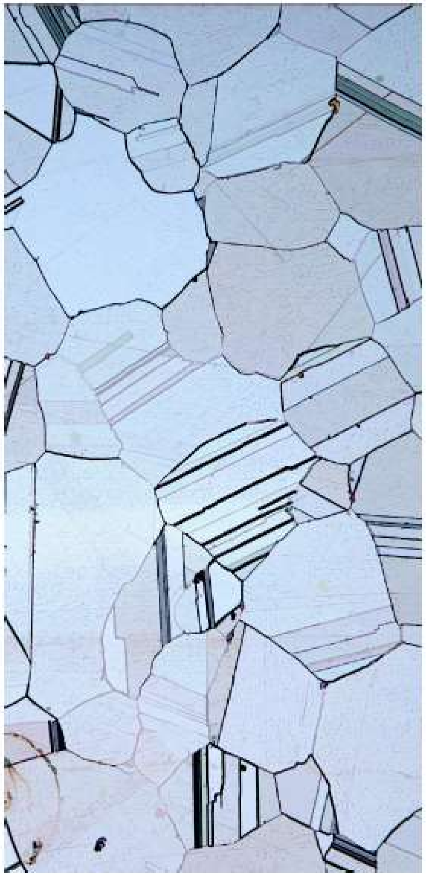




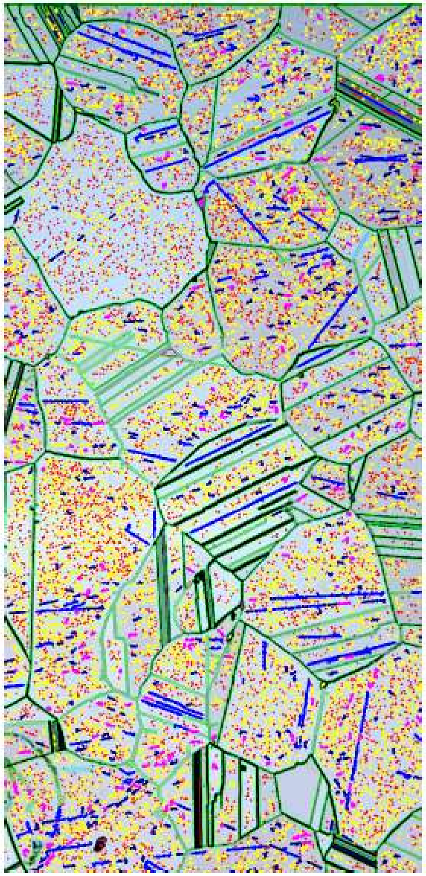




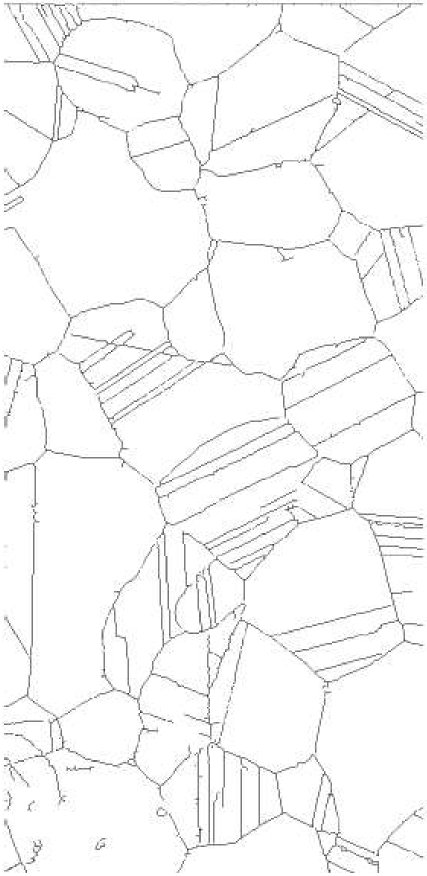
Micrographs of super-alloy: segmentation



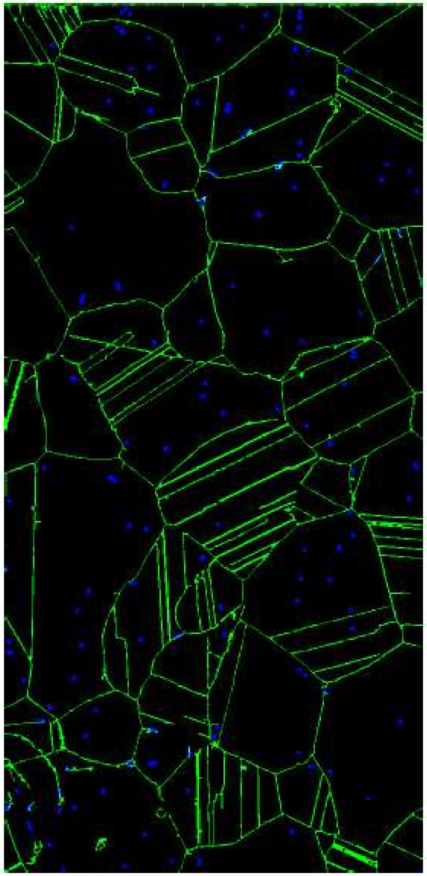
a) Vstupný obraz - príklad



b) Výsledok klasifikácie

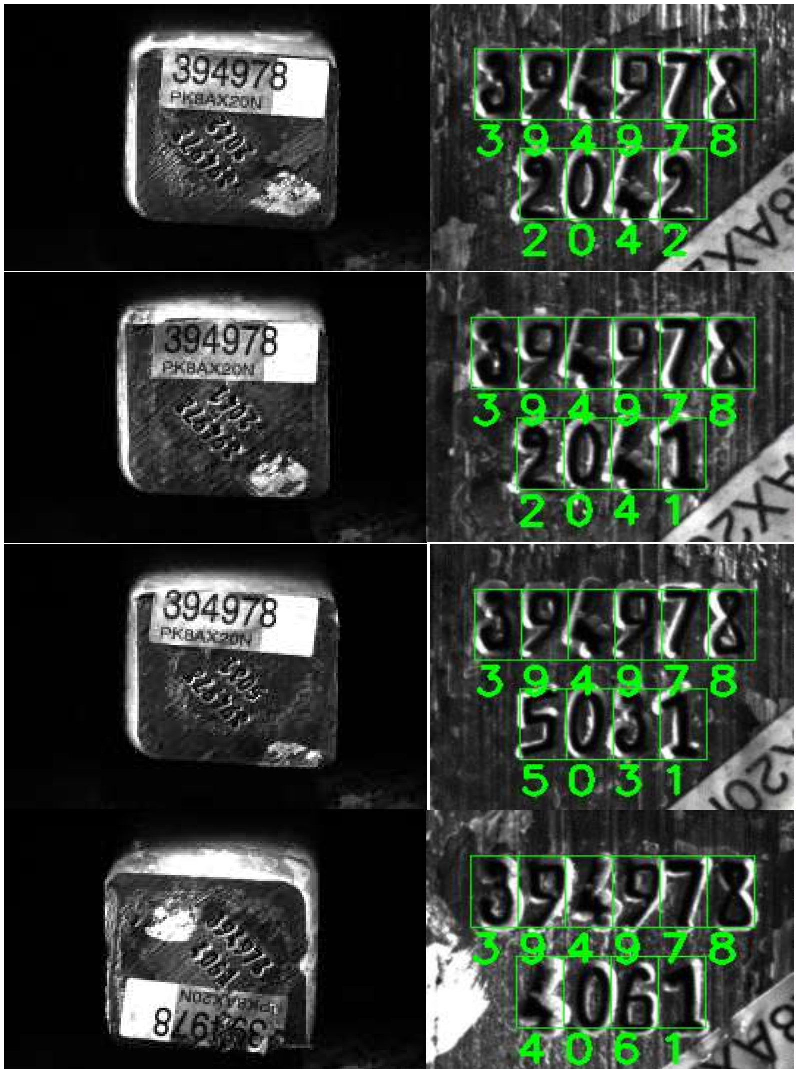


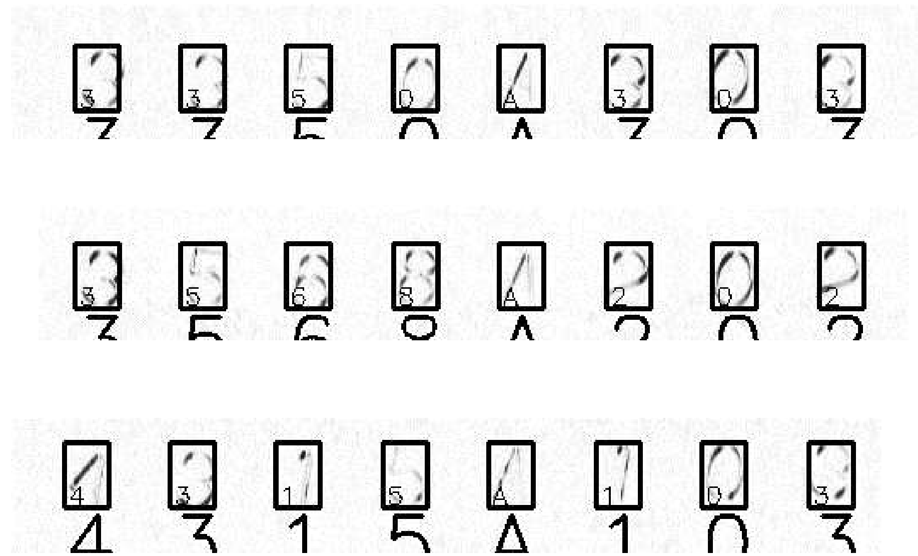
c) Generovaný hranový obraz

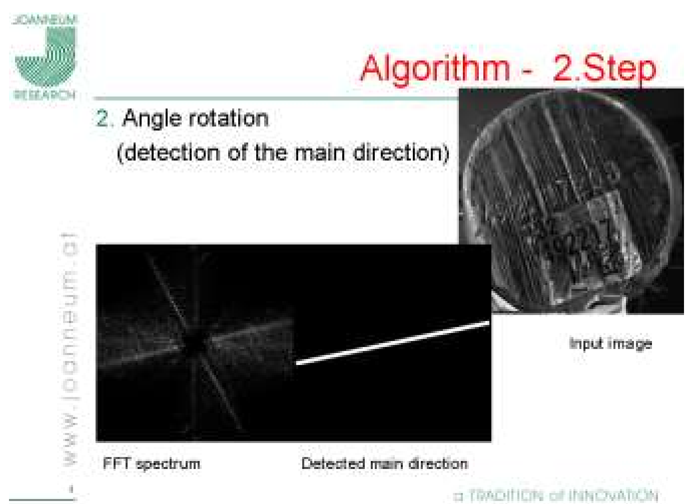


d) Hrany (zelené) a delta-fáza (modrá)

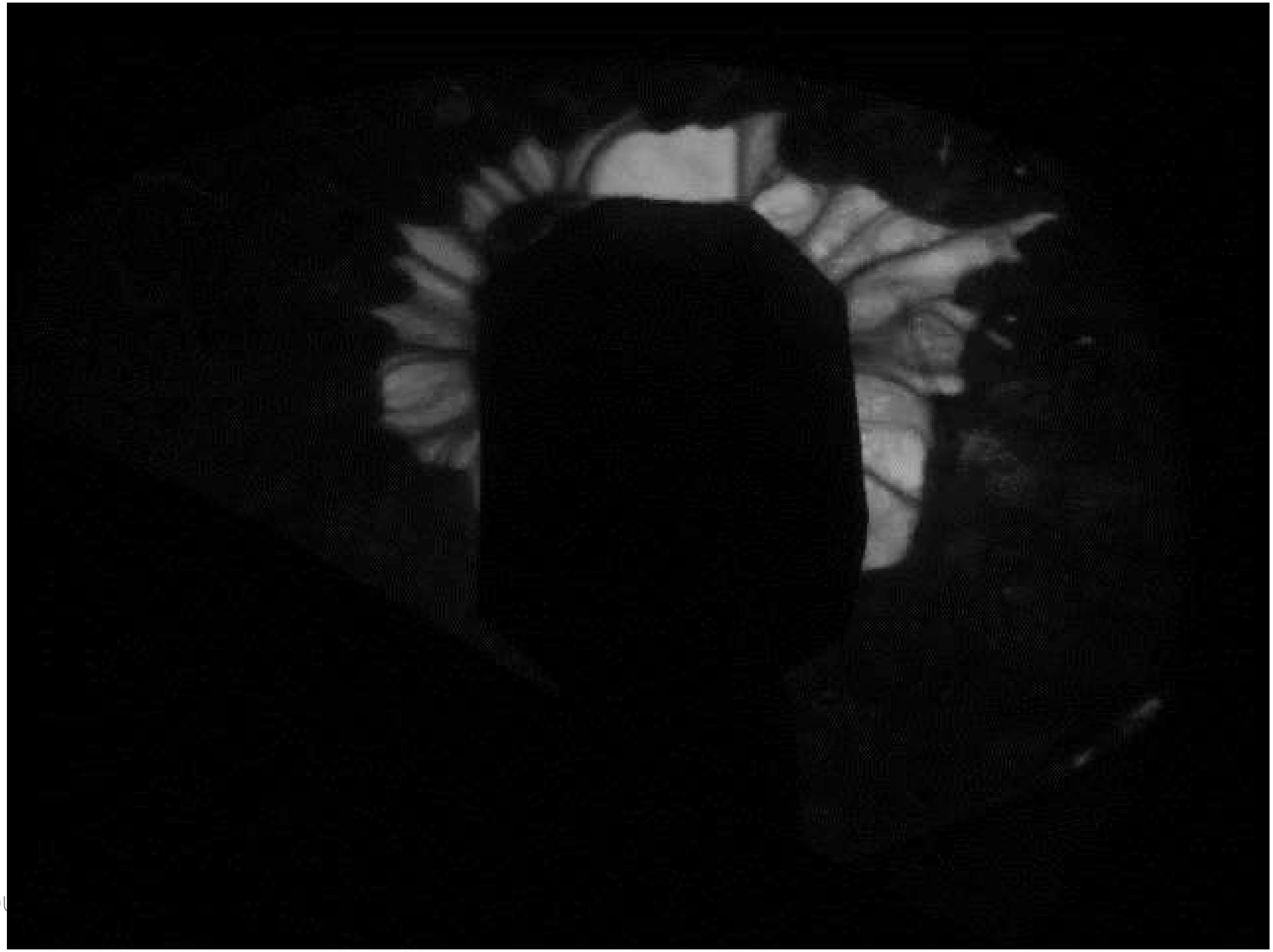
Industrial OCR







Industrial quality inspection – Slag temperature and flow monitoring system



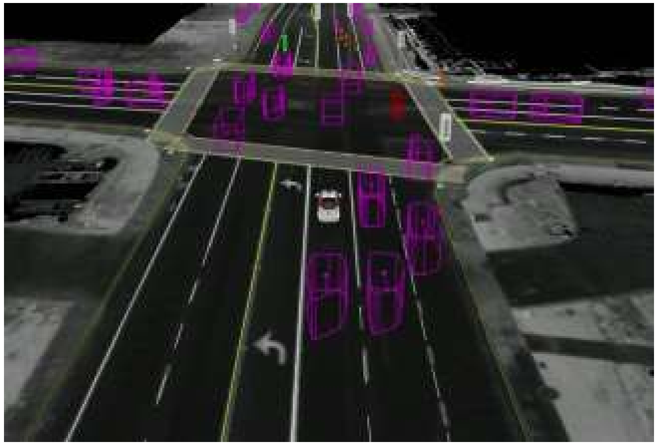
Traffic applications

- Self-driving cars
- Car detection
- Pedestrian detection
- Traffic surveillance
- Traffic statistics
- Section speed measurement
- Accident detection

Self-driving cars: Problems

Where is the car?

What is around the car?



What will happen next?

What should the car do?

Source: The Dream of Self-Driving Cars, Sebastian Ramos, Daimler R&D, Environment Perception, Vehicle Automation and Chassis Systems

Self-driving cars: The role of computer vision (some examples)

Complementing the map

Recognize objects to interact with them

Understanding what others are doing

Sometimes it is the only solution

Source: The Dream of Self-Driving Cars, Sebastian Ramos, Daimler R&D, Environment Perception, Vehicle Automation and Chassis Systems

Self-driving cars

Google Self-Driving Car Project (since 2009)

self-driven cars - more than 2 million miles mostly on city streets

https://waymo.com/tech/

CV for Autonomous Driving

STEREO_VISION

SENSOR_FUSION

SEMANTIC_SCENE_UNDERSTANDING

MAPPING

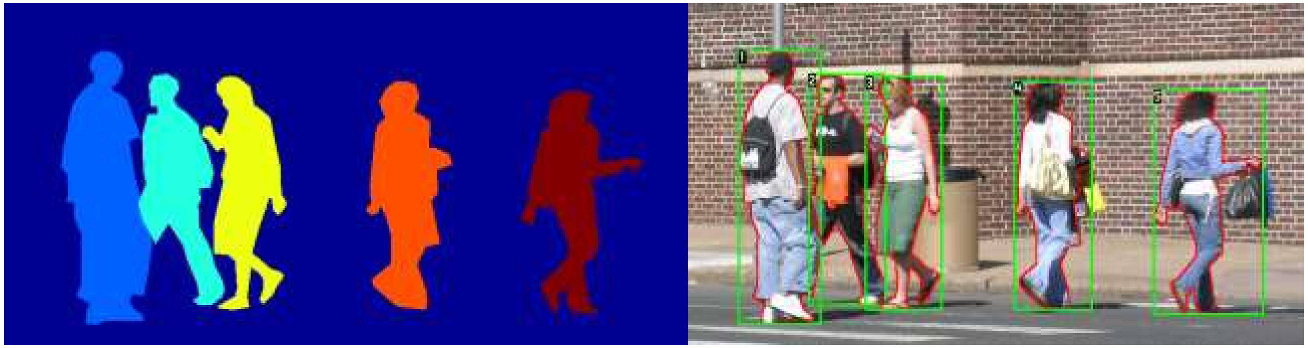
LOCALIZATION

SENSOR_REGISTRATION

DEEP_LEARNING_TOOLS

https://sites.google.com/site/cvadtutorial15/materials

Pedestrian detection, tracking in video



3D

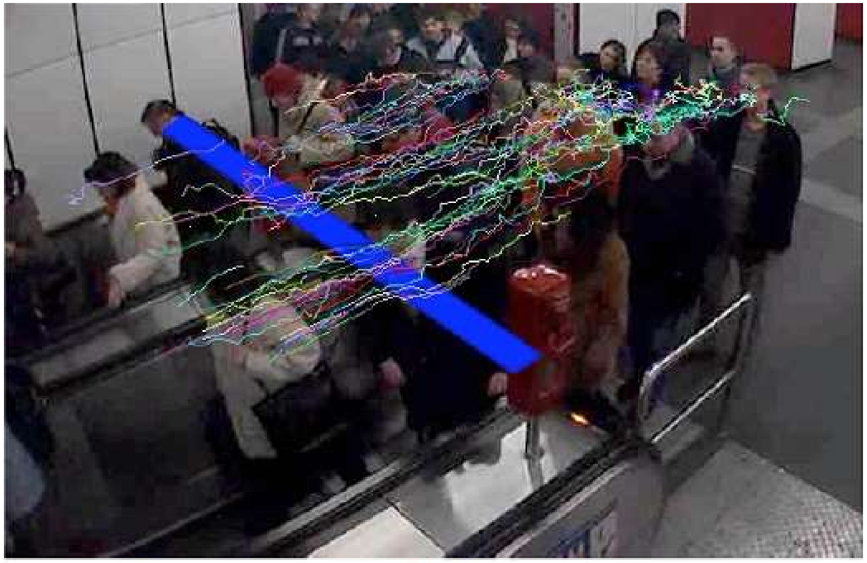
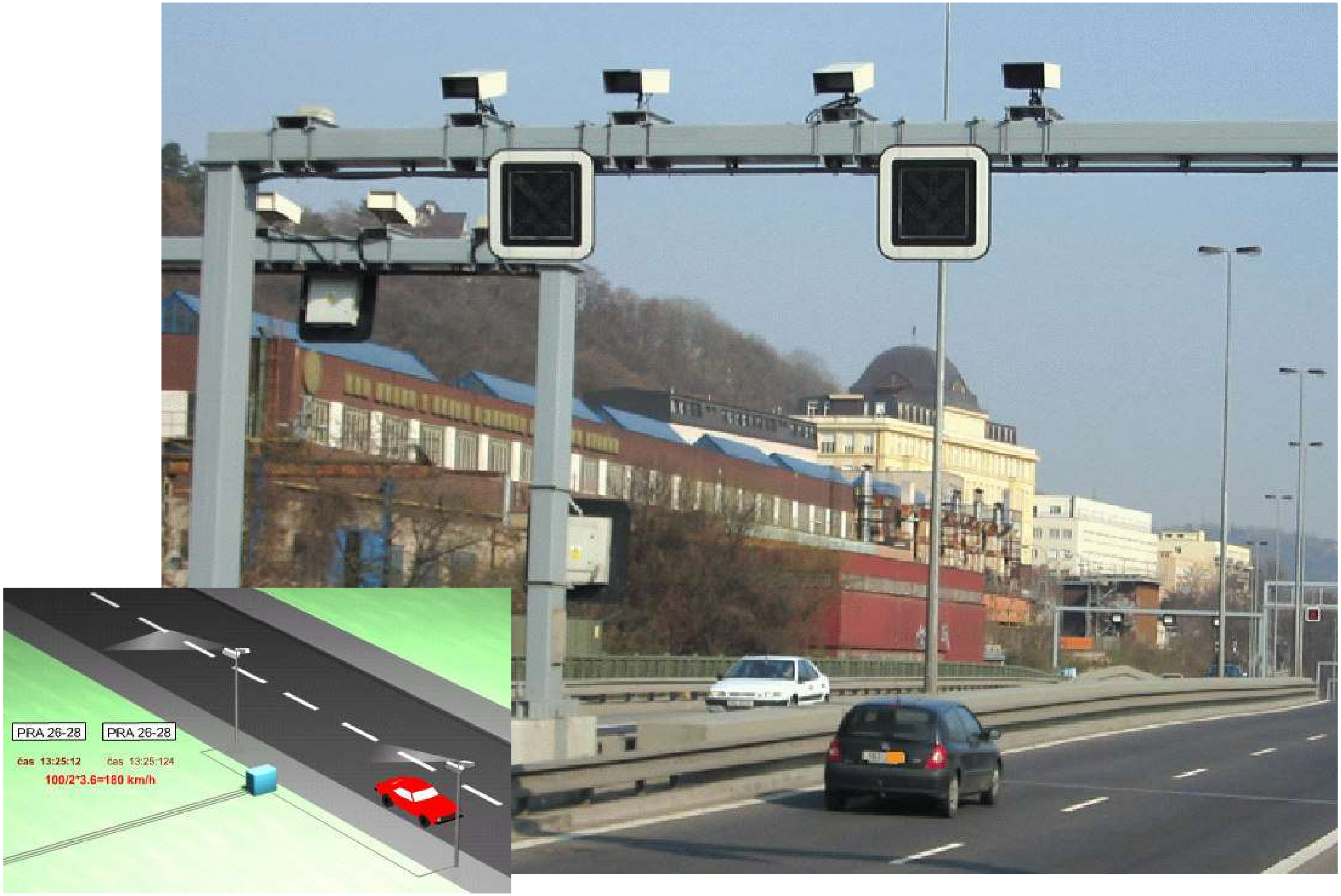


Figure 1. Crowded Scene in an Underground Station. Pedestrians which cross the bright (blue) line at the foot of the elevator are being counted in this scenario.

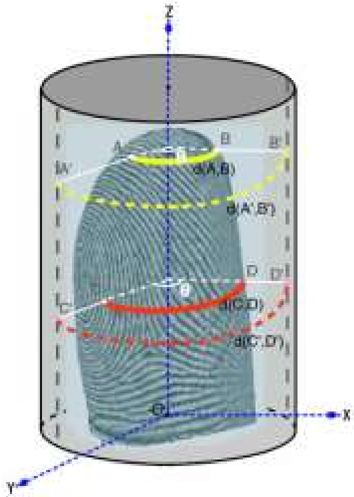
Section speed measurement

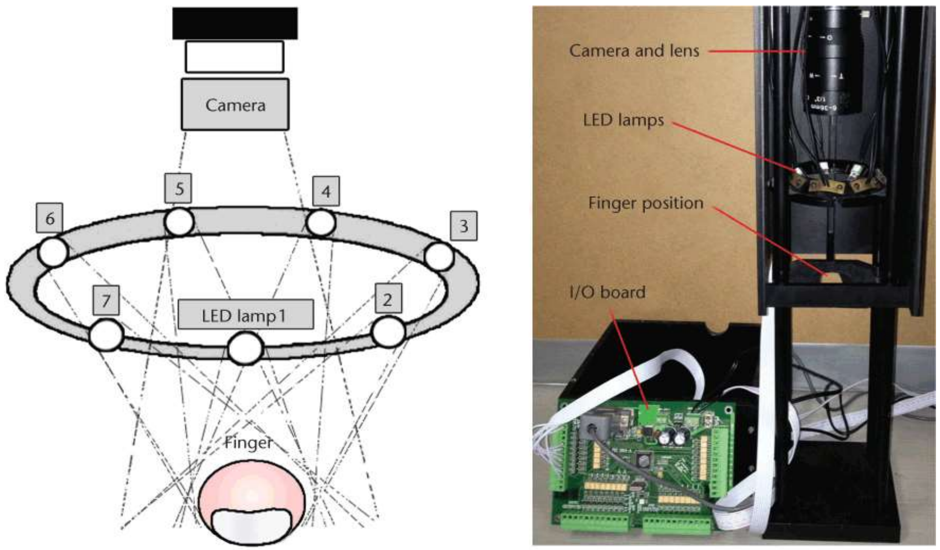


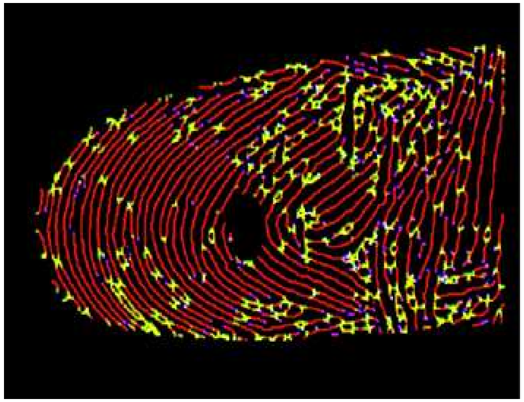
Road sign detection

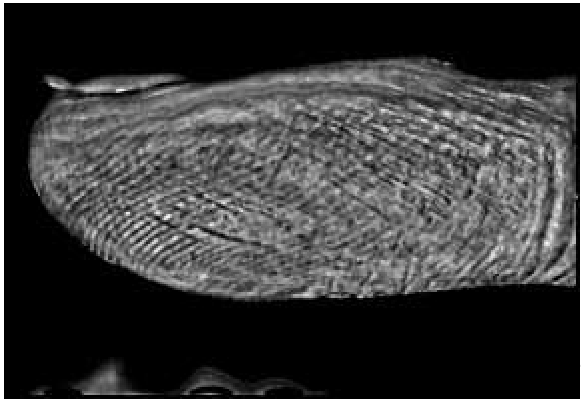
Security – project example
3D touchless fingerprint

3D touchless fingerprint







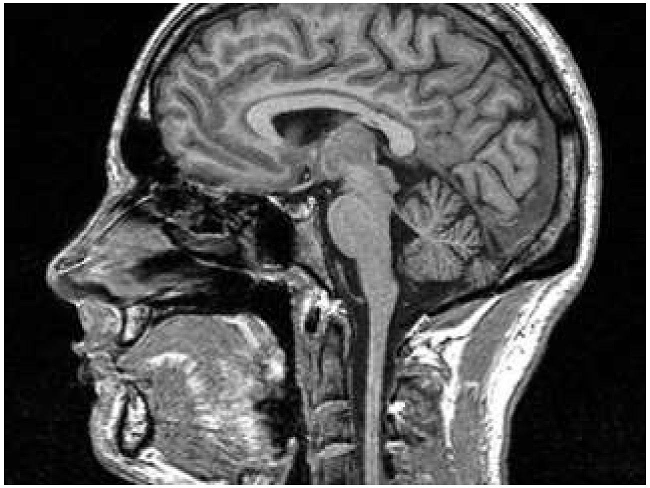


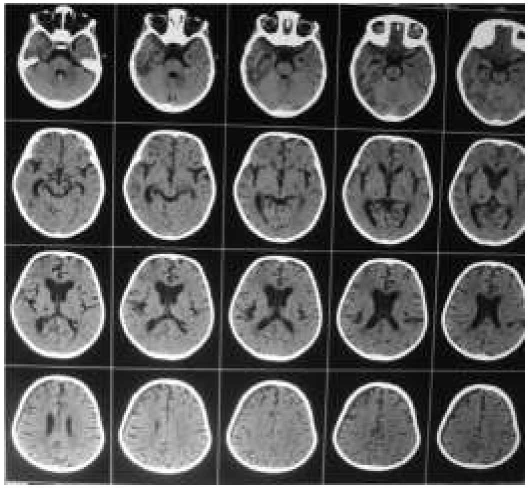
The Moon - NASA

The colors in this image are "enhanced," in the sense that the camera Galileo used to photograph the moon was sensitive to near infrared wavelengths of light beyond human vision.

Medical imaging

First things first – medical imaging





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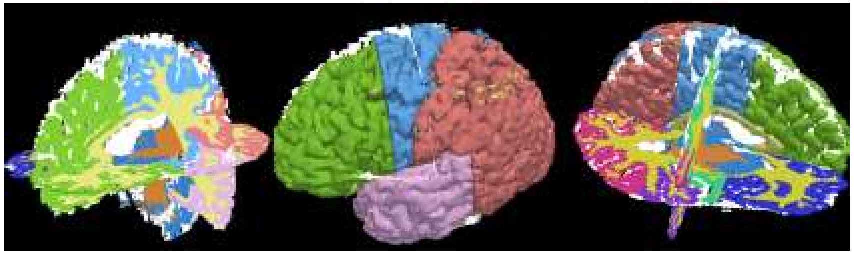
http://www3.gehealthcare.in/~/media/images/india/pet-ct/pet-ct_scanners/discovery_pet-ct_610/discovery_pet_ct_610_spolight3.jpg,
http://cdn1.medicalnewstoday.com/content/images/articles/245491-ultrasound-probe.jpg,
https://www.researchgate.net/profile/Kharosekar_Hrushikesh/publication/270294924/figure/fig4/AS:295220458606595@1447397450872/Fig-4-e-CT-brain-12-h-after-2nd-scan-showing-complete-disappearance-of-SDH.png,

Why is medical imaging so special?

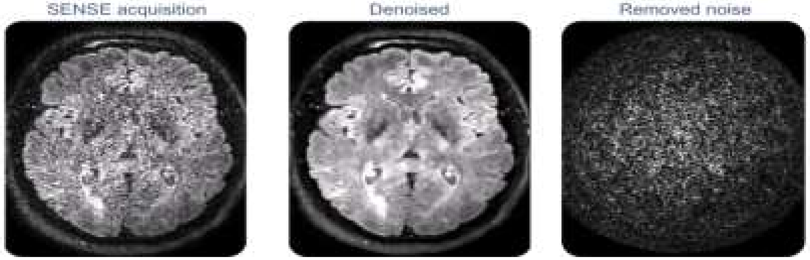
- Different kind of data
- 2D -> 3D
- If something goes wrong.. well.. it rather should not
- Different interpretation of images
    - Color is not always color

CV and Medical imaging – use cases

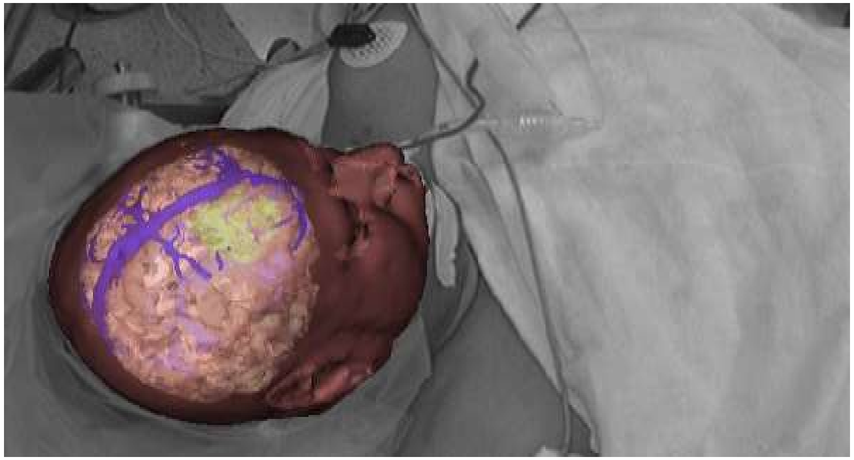
Segmentation



Noise removal



Registration



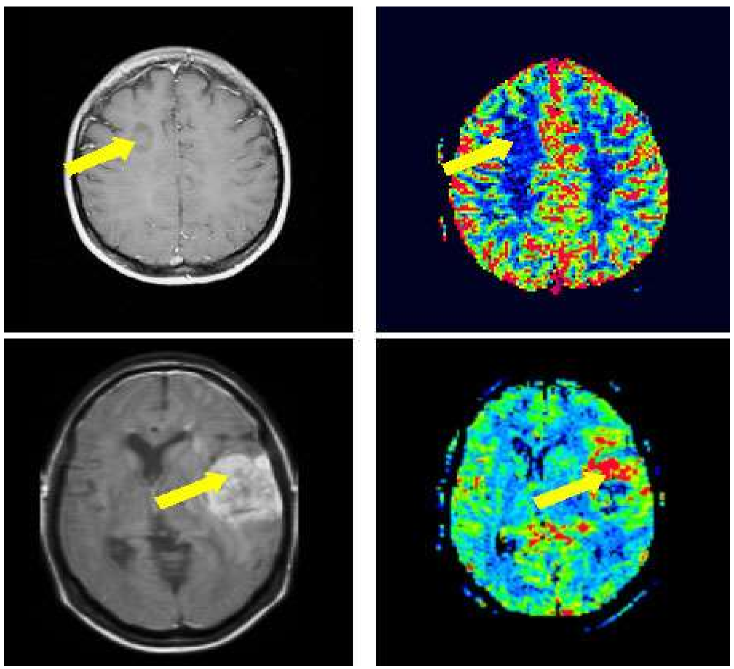
Reconstruction

https://www.youtube.com/watch?v=OjojD4jc9u8

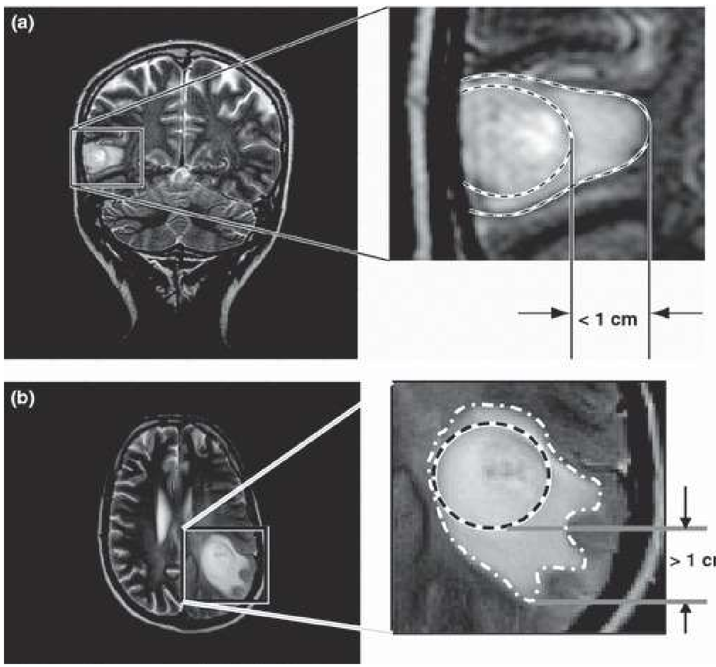
https://sites.google.com/site/pierrickcoupe/softwares/denoising-for-medical-imaging/AdaptiveDenoising.jpeg?attredirects=0
https://www.slicer.org/w/images/0/0f/Image-views-3D.png
http://www.spl.harvard.edu/archive/spl-pre2007/pages/papers/horizon/1c.jpg

CV and Medical imaging – use cases

Detection



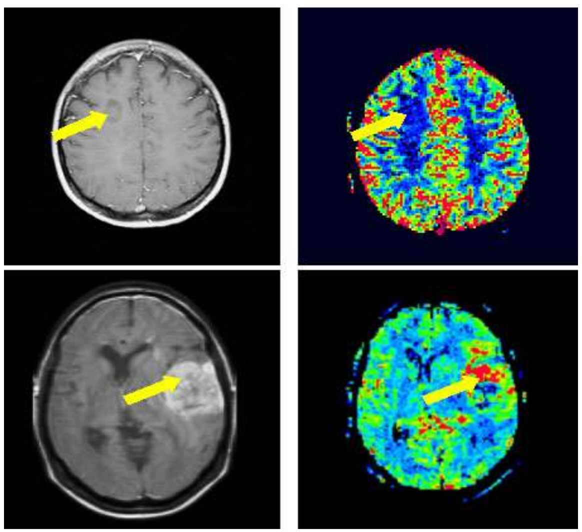
Measurement



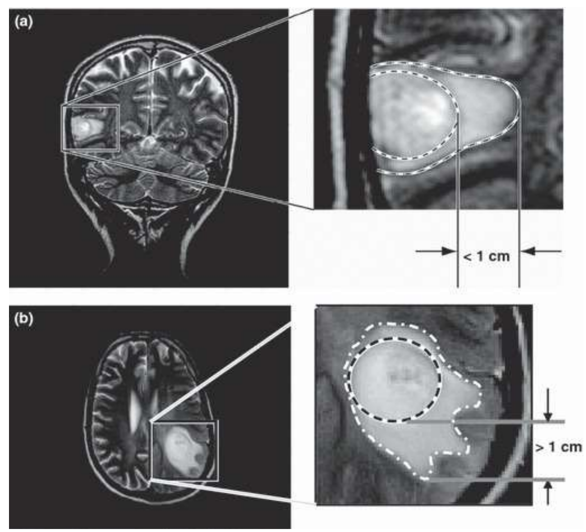
https://www.leidenuniv.nl/en/researcharchive/content_images/research/nieuwsbriefppt-2.jpg
https://www.researchgate.net/profile/Wolfgang_Grisold2/publication/26244727/figure/fig2/AS:267894474932261@1440882428722/Figure-1-Measurement-of-peritumoral-edema-by-means-of-MRI-T2-coronalaxial-weighted.png

CV and Medical imaging – use cases

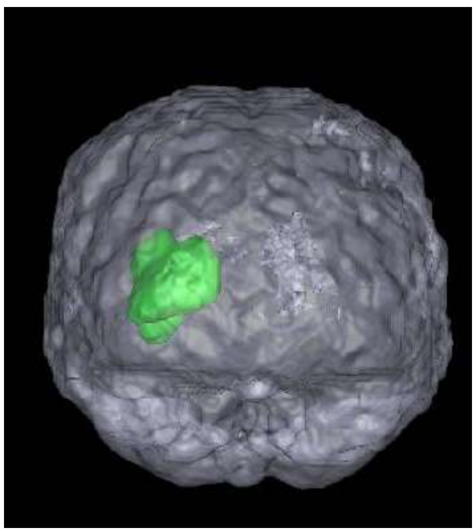
Detection



Measurement



Preprocessing for visualization



https://www.leidenuniv.nl/en/researcharchive/content_images/research/nieuwsbriefppt_2.jpg
https://www.researchgate.net/profile/Wolfgang_Grisold2/publication/26244727/figure/fig2/AS:267894474932261@1440882428722/Figure-1-Measurement-of-peritumoral-edema-by-means-of-MRI-T2-coronalaxial-weighted.png

CV and Medical imaging – why?

- Save time
    - E.g. manual segmentation takes huge amount of time
- Prevent human failure
    - Everyone can make a mistake
- Recommend something
    - E.g. “look there, there’s some anomaly”
- Simplify doctor’s life
    - Show him/her only the important stuff

Take-home message

- Medical data is produced by wide range of modalities
- Images in medical imaging are quite different
  - Intensities mostly represent some physical quantity
- CV is often a preprocessing step for further analysis of medical data
- If used well, it can save huge amount of time and labour

Live demo

- 3D Slicer
- Siemens prototype

Visual data acquisition

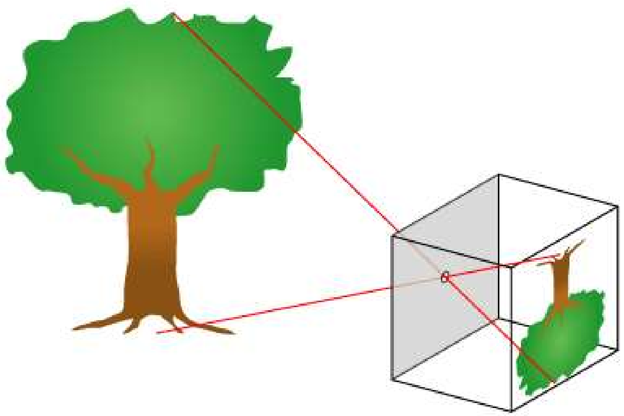
Historical milestones

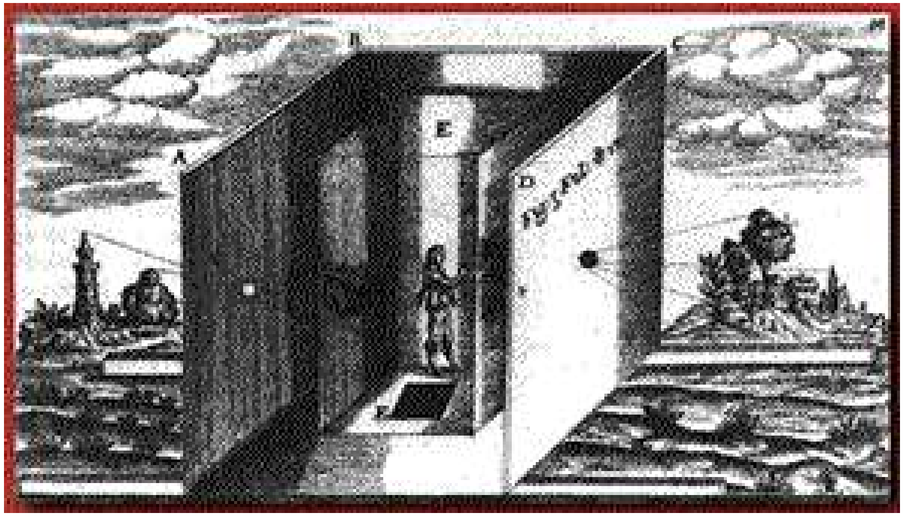
Pinhole camera (Camera obscura)

Aristotle - in the 4th century BC…

Leonardo da Vinci - in 15th century

It was simply a darkened room, to which light was admitted only through a single small hole in the window shutter.





http://www.precinemahistory.net/index.html

Historical milestones - Kinetoscope

1889 - THOMAS ALVA EDISON

Edison's Kinetoscope

The **Kinetoscope** was a device that gave the impression of movement by moving an endless loop of film continuously over a light source with a rapid shutter.

48 images/sec

Historical milestones – Digital Image Transmission

Bartlane cable picture transmission system

Conversion in digital form - 5 Bit

This system was invented in 1920 and the first trans-Atlantic cable picture was transmitted in 1921, between London and Halifax

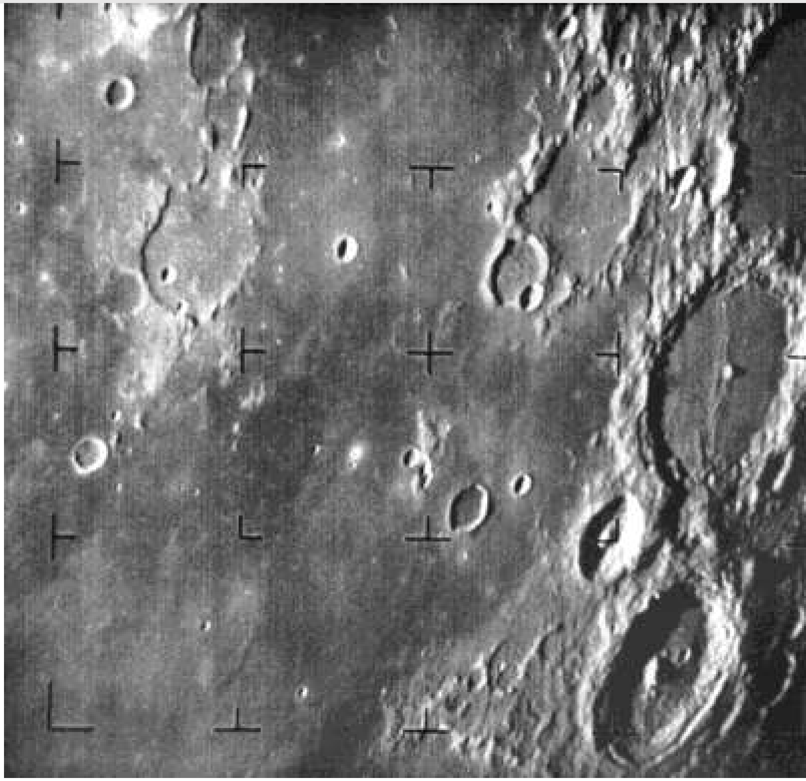
Picture Transmitted and Reproduced by the Bartlane System.

Historical milestones – Computer image processing

1964 : the birth of digital image processing

Image processing using computers

NASA project



The first picture of the moon by a U.S. spacecraft. Ranger 7 took this image on July 31, 1964 (NASA.)

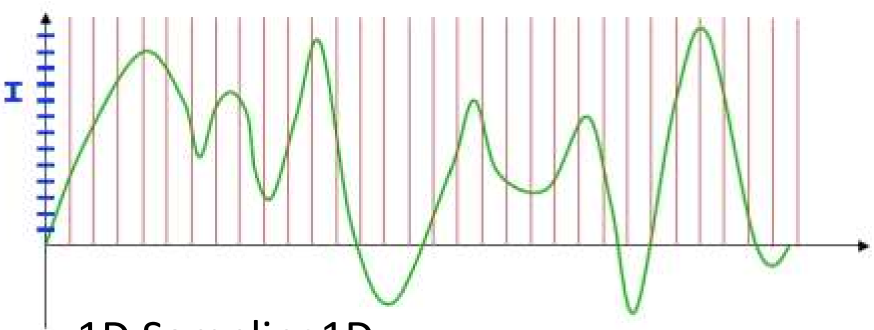
What is an image?

A gray-scale image can be defined as a two-dimensional function F=f(x, y)

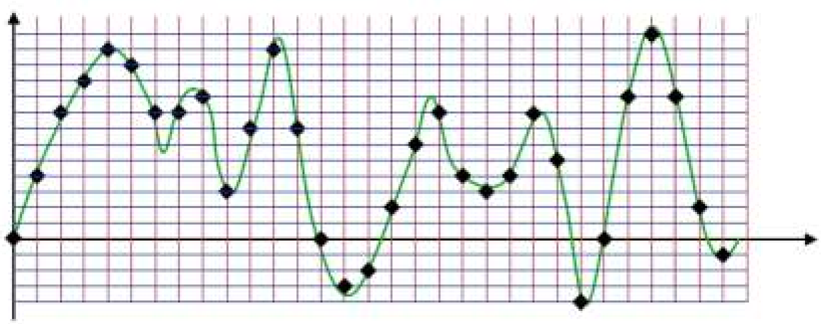
- x and y are spatial (plane) coordinates

- The amplitude F of f(x, y) is the intensity of gray level
  - Intensity: jas, intenzita

Analog to digital conversion – Digitisation: Sampling & Quantization

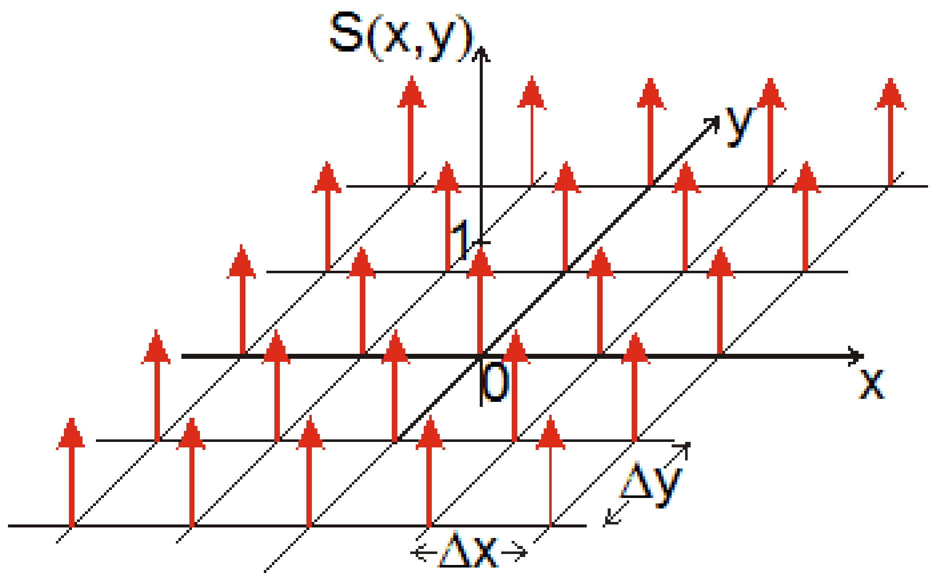


1D Sampling1D



1D Sampling & Quantization

2 D Sampling1D



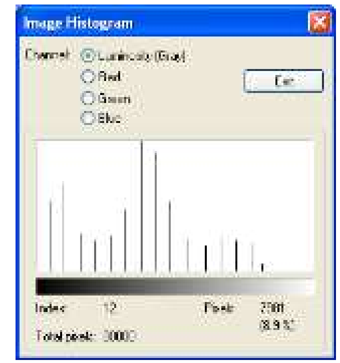
Dynamic Range & Gray-Level Resolution

Dynamic range describes the ratio between the maximum and minimum measurable light intensities (white and black, respectively)

The **number of gray levels** after digitization is typically an integer power of 2

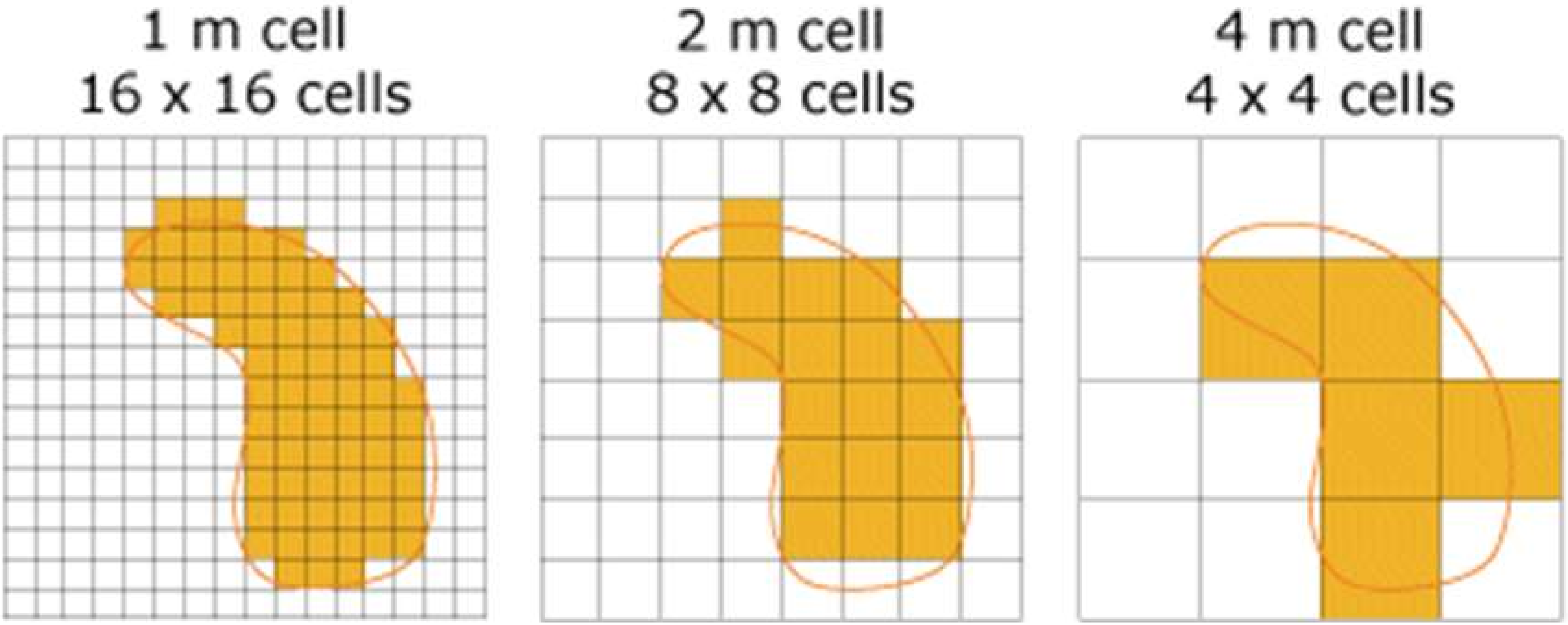
- $L = 2^k$

Dynamic range - Lena example



Spatial resolution

Number of cells in x and y direction



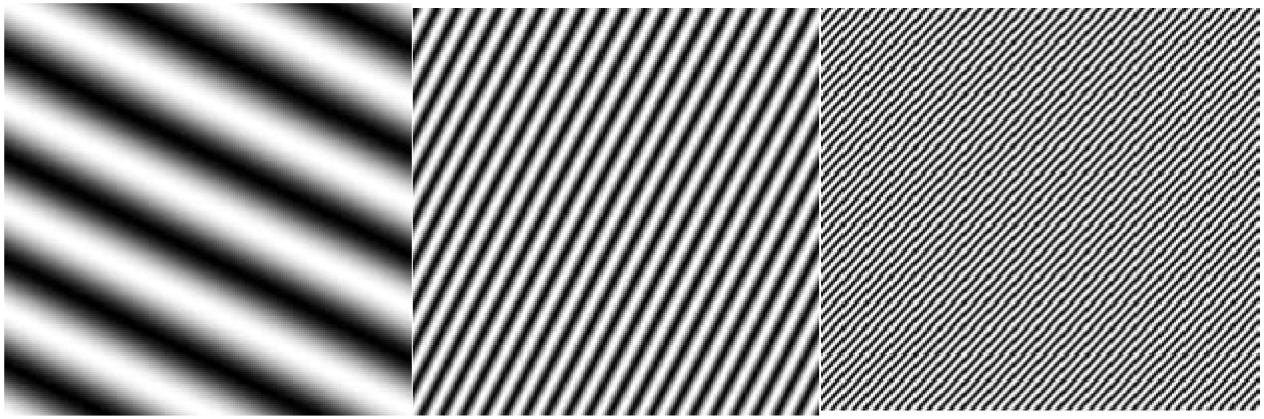
Nyquist sampling theorem

The sampling frequency should be at least twice the highest frequency contained in the signal.

- fs > 2 fmax

Frequency in the image – examples

Low -> -> High



Sub-Nyquist sampled image – Moiré pattern

Sub Nyquist sampled image showing a Moiré pattern

Dimension of Image Matrix

Gray-scale image	m x n x 1
Colour image	m x n x 3
Colour image + alpha (opacity) channel	m x n x 4
Multi-spectral image	m x n x x

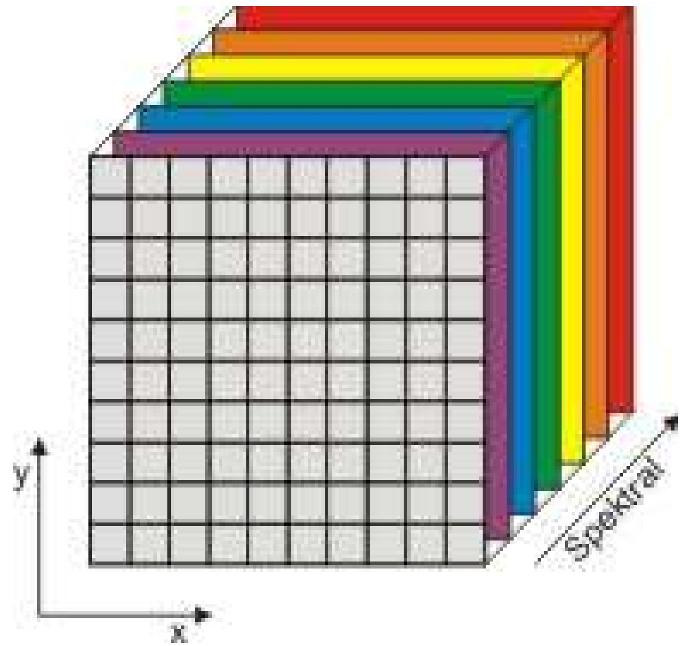


Image sequence – video

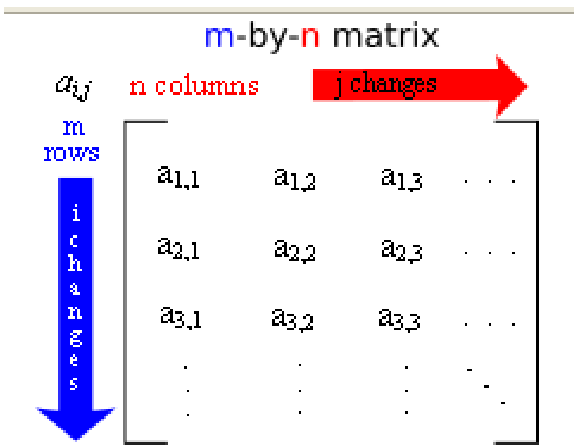
Additional dimension – **time**

Frequency of images [frames/sec]

- Human sensing ~ approx. min. 10 frames/sec

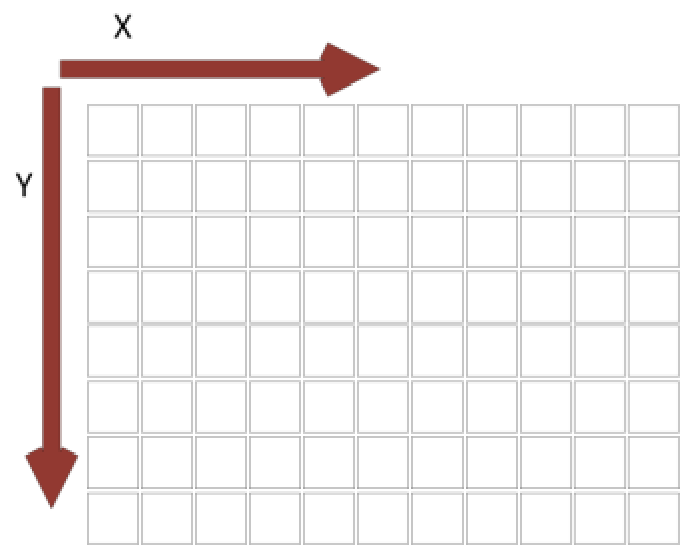
Matrix Representing of Digital Image

The result of sampling and quantization is a matrix of numbers



=> matrix operations

Coordinate convention of an array (image libraries)



Visual data

Visible light

Infrared

Ultrasound

Radar

CT, MRI , Röntgen

Depth image

...and more

Visible light

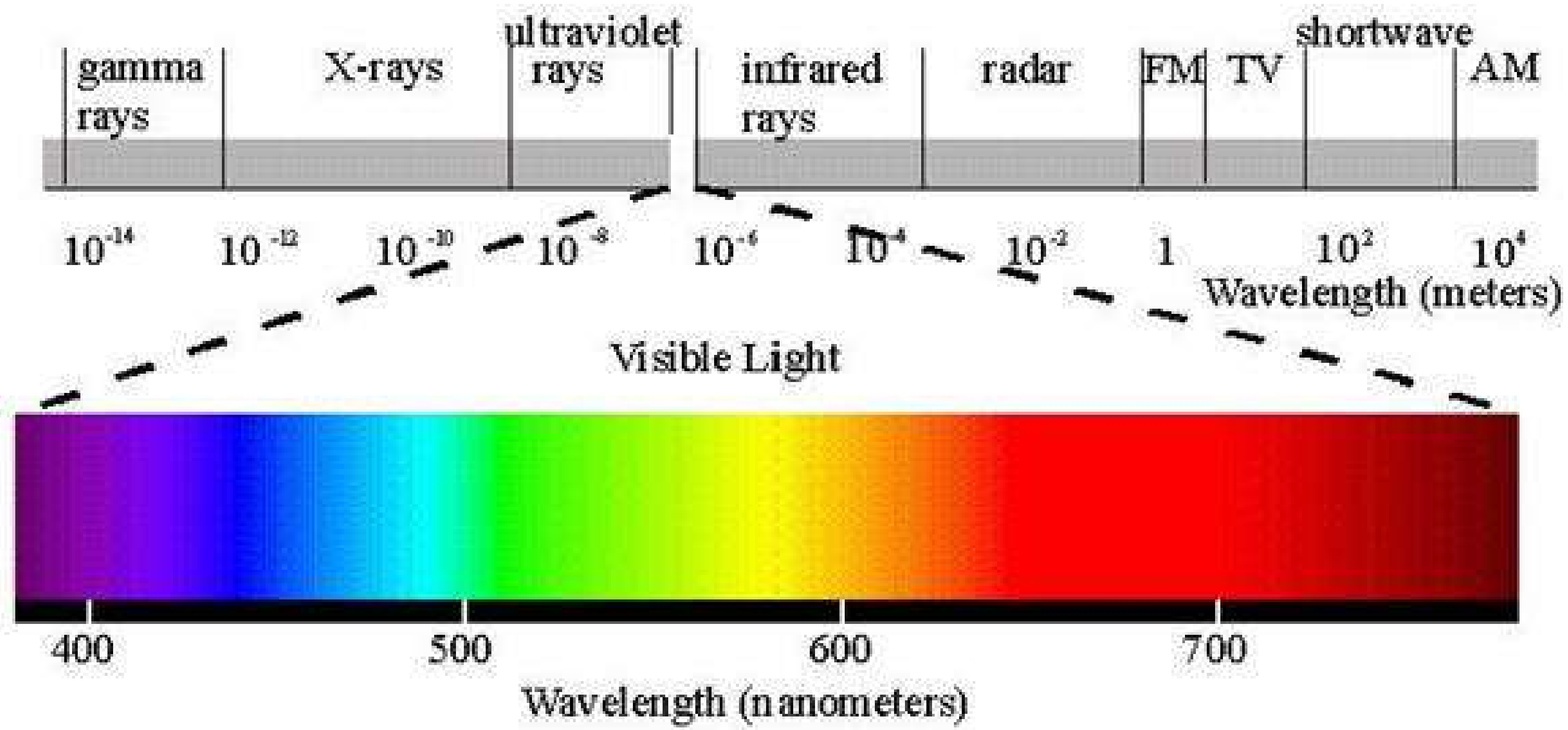
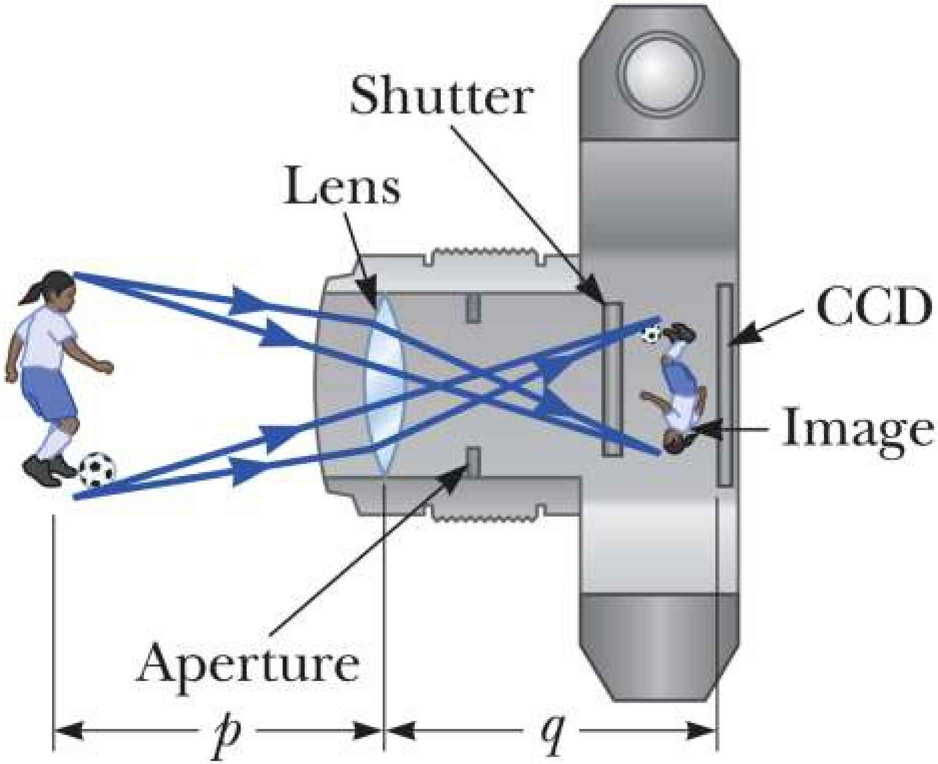


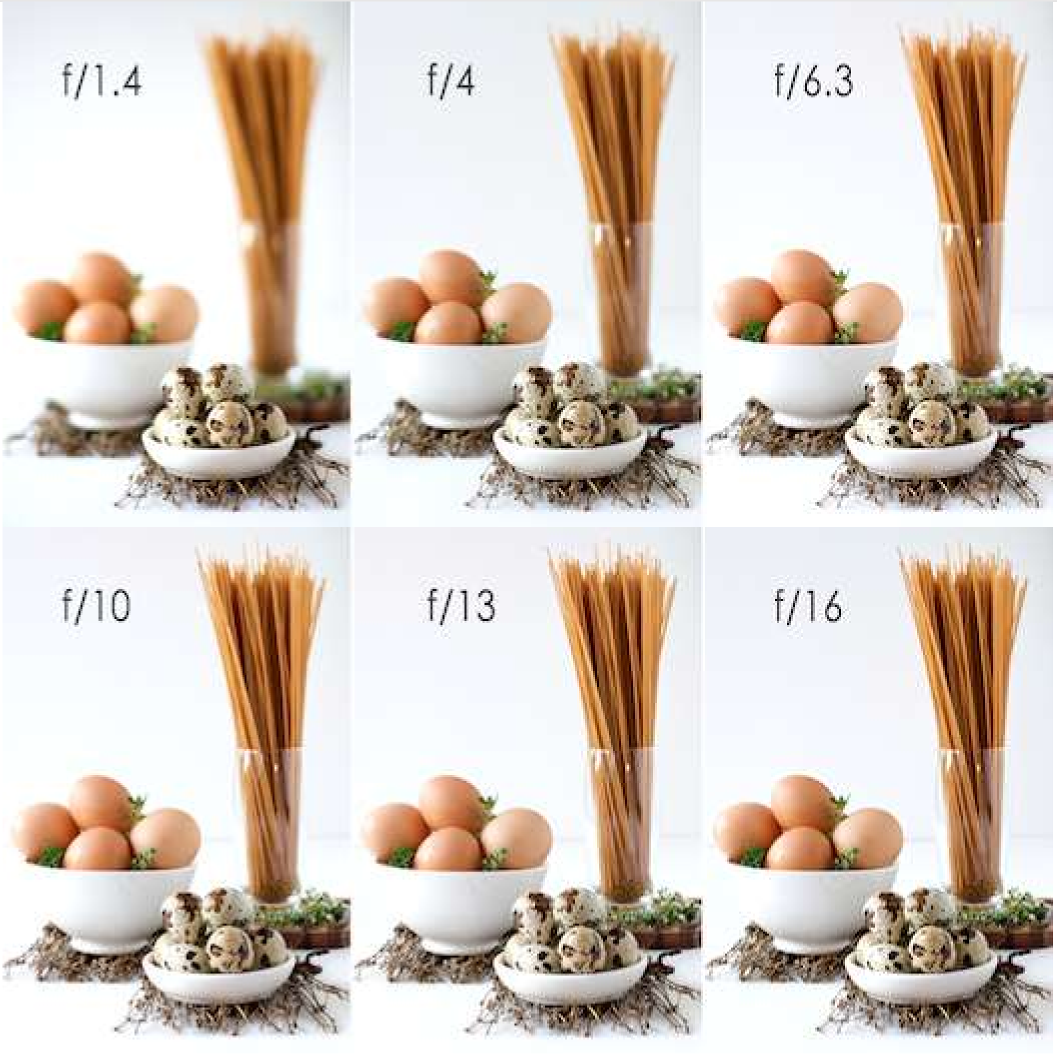
Image acquisition - camera

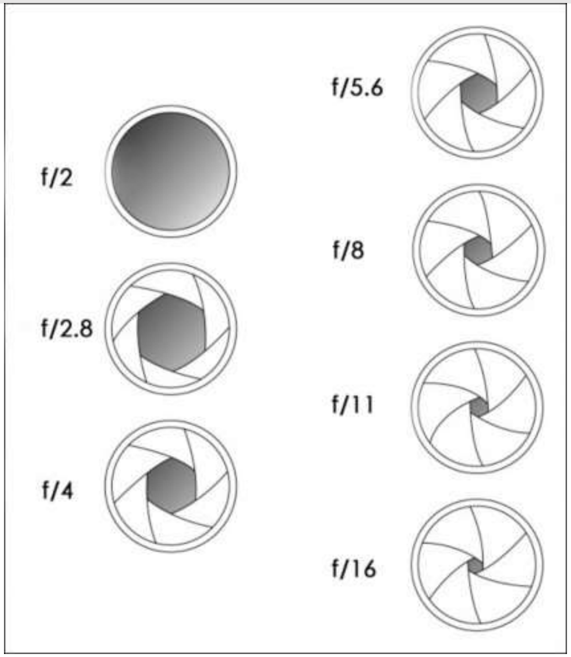


Optical sensor:

- CCD (Charged Coupled Device)
- CMOS (Complementary Metal Oxide Semiconductor)

Image acquisition - Depth of Field



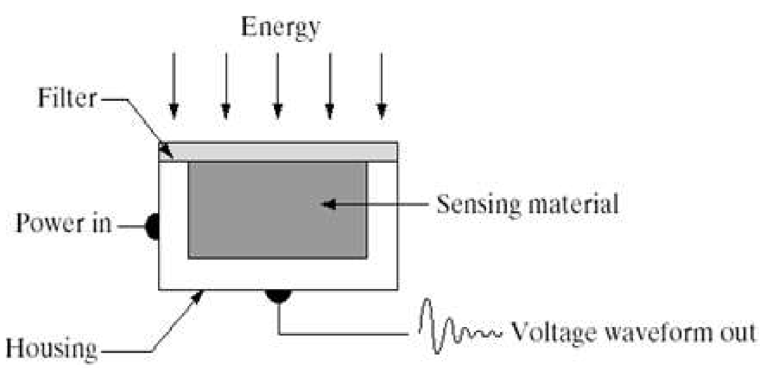


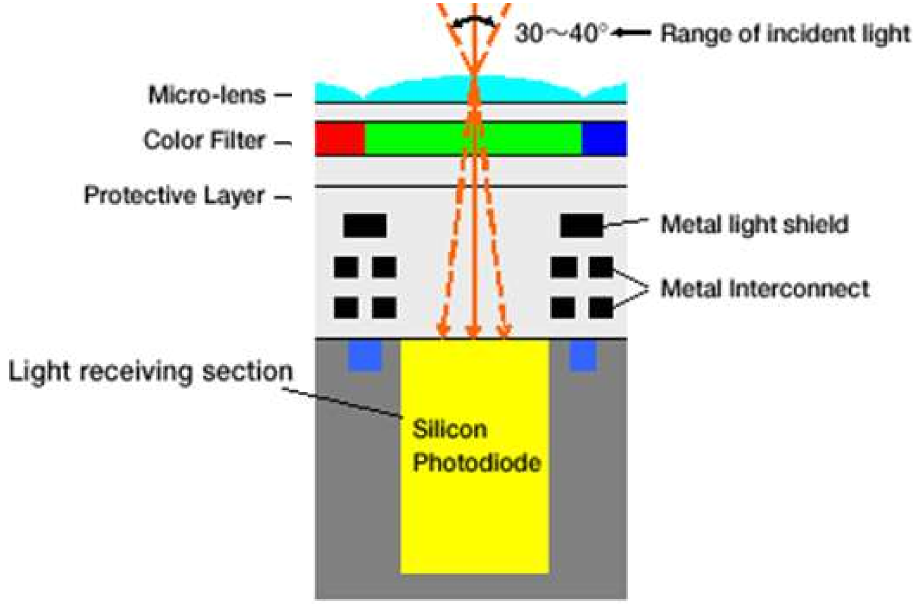
Aperture

Image sensor – single unit

Image Sensor

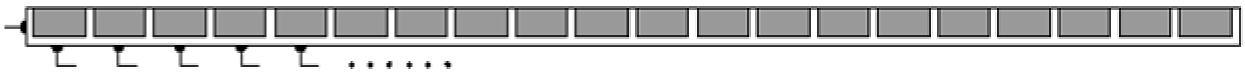
- Physical device that is sensitive to the energy radiated by the object we wish to image



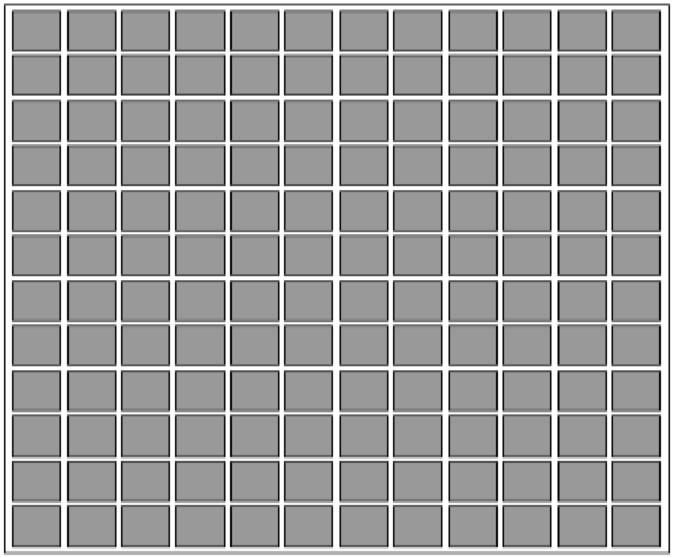


Conventional image sensor

Principal Sensor Arrangements

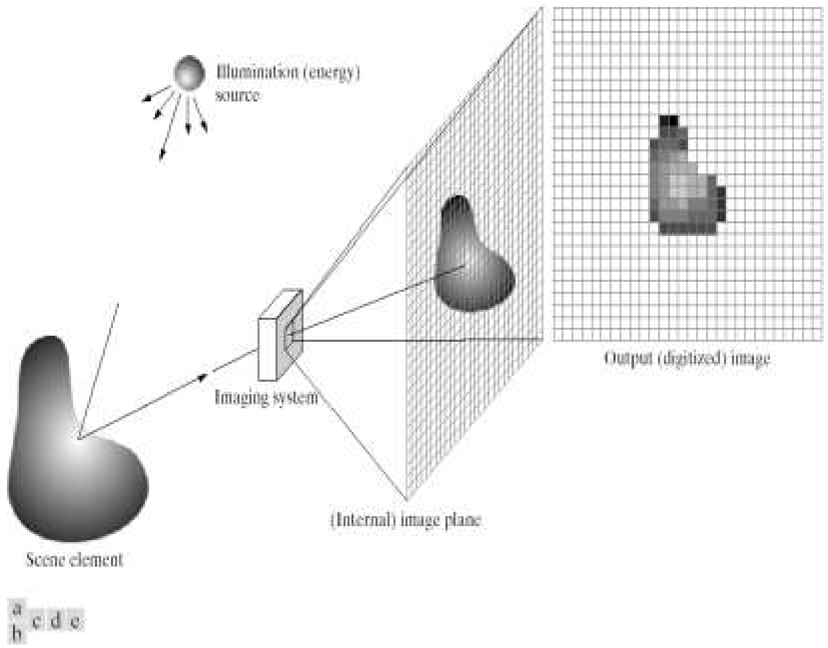


Line sensor



Array sensor

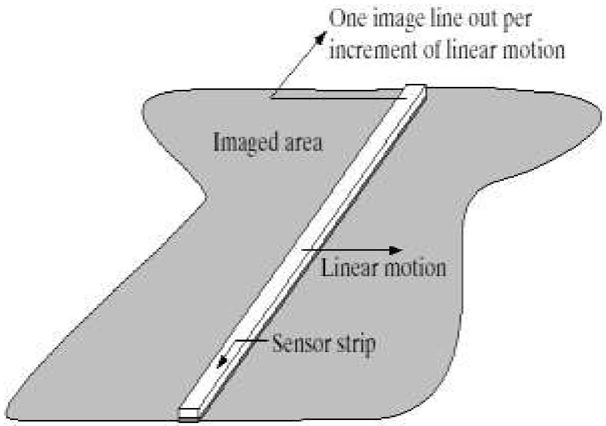
Image Acquisition Using Sensor Arrays



A typical sensor for the cameras is a CCD/CMOS array

(a) Illumination source.
(b) An element of a scene.
(c) Imaging system.
(d) Projection of the scene onto the image plane.
(e) Digitized image.

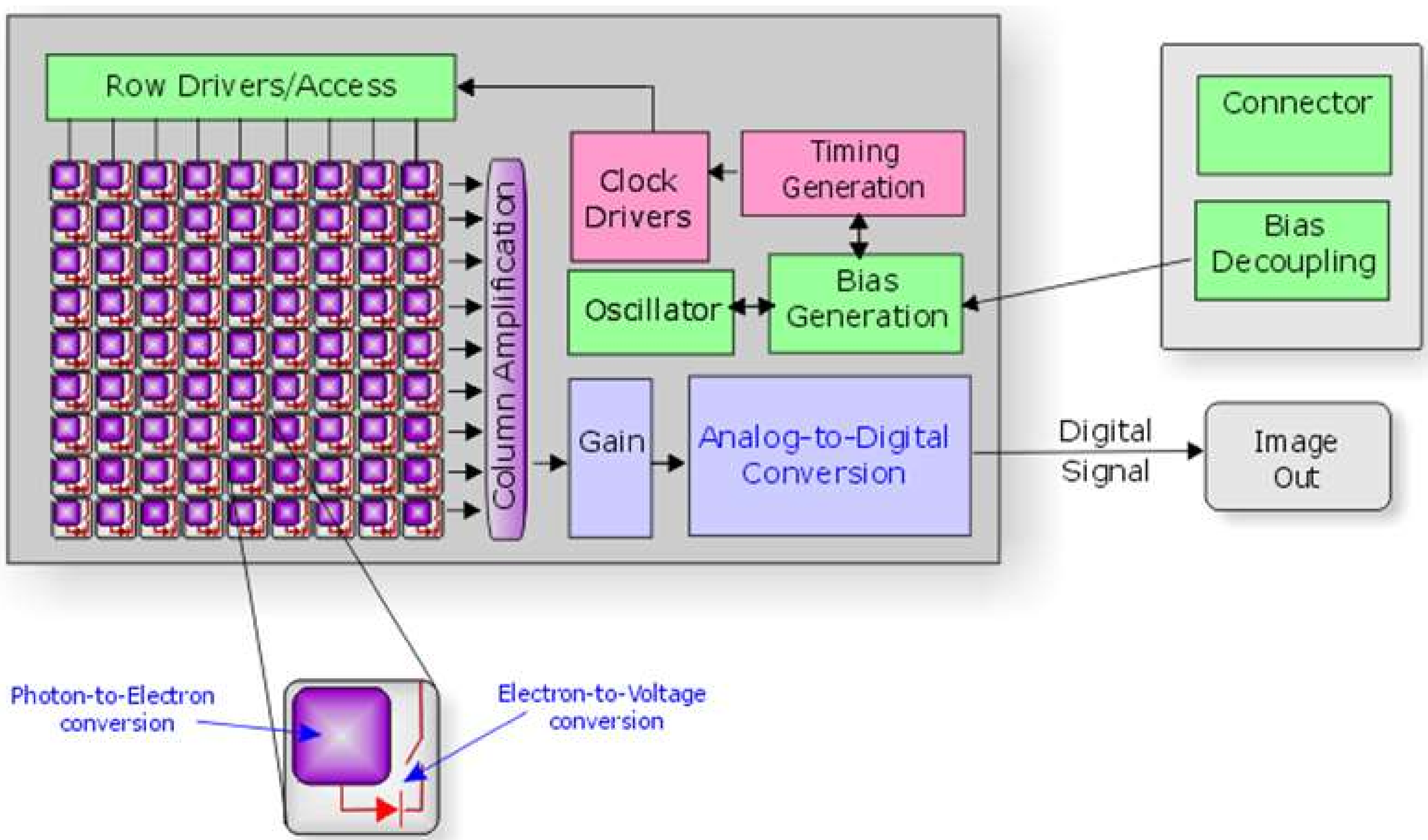
Line scan camera



The imaging strip gives one line of an image at a time, and the motion of the strip completes the other dimension of
a two-dimensional image.

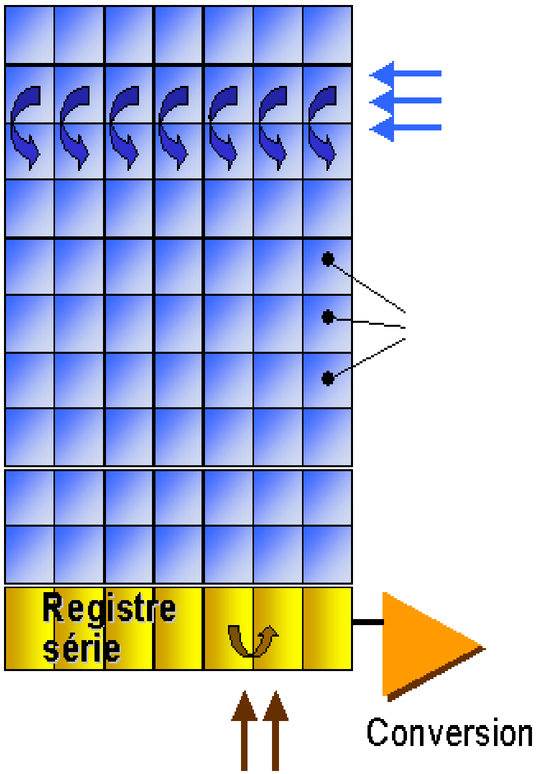
CMOS Sensor

Each pixel contains a photodetector – can be read separately



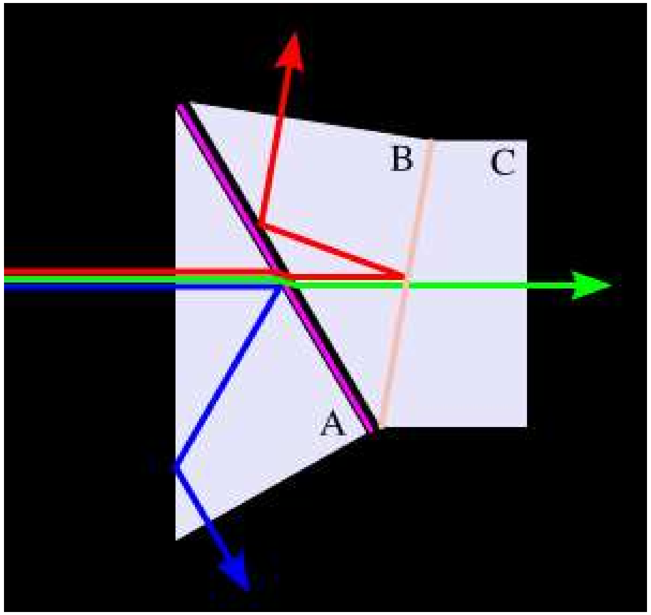
CCD-Sensor

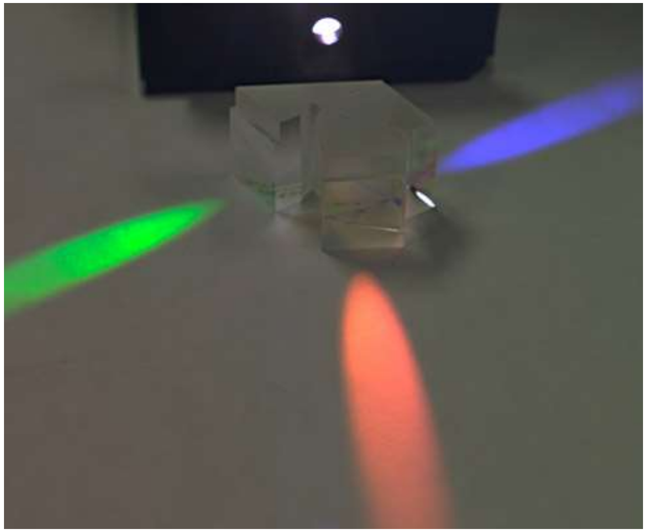
In a CCD device, the charge is actually transported across the chip and read at one corner of the array.



RGB -Prism Based Imaging

A color-separation beam splitter prism



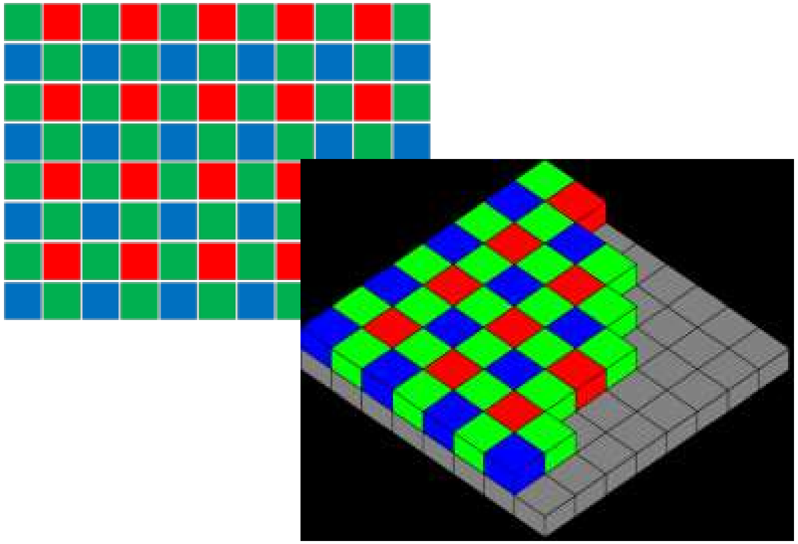


Three sensors
3CCD Colour line scan cameras

RGB -Bayer matrix

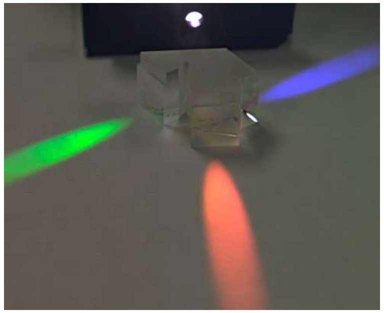
Bayer matrix

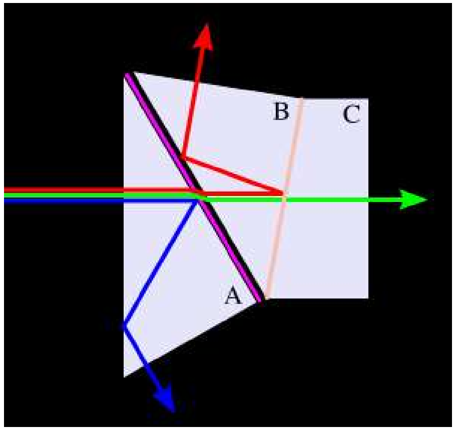
- The Bayer arrangement of color filters on the pixel array of an image sensor.



Three-CCD

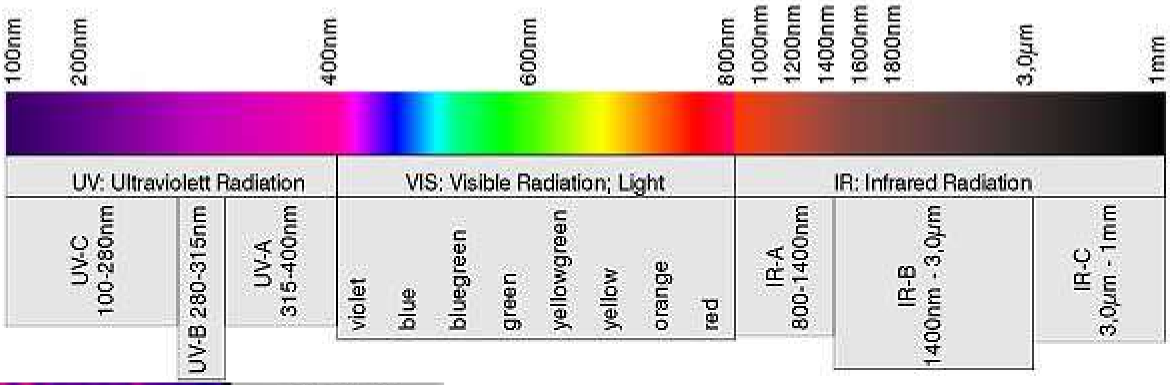
- A color-separation beam splitter prism

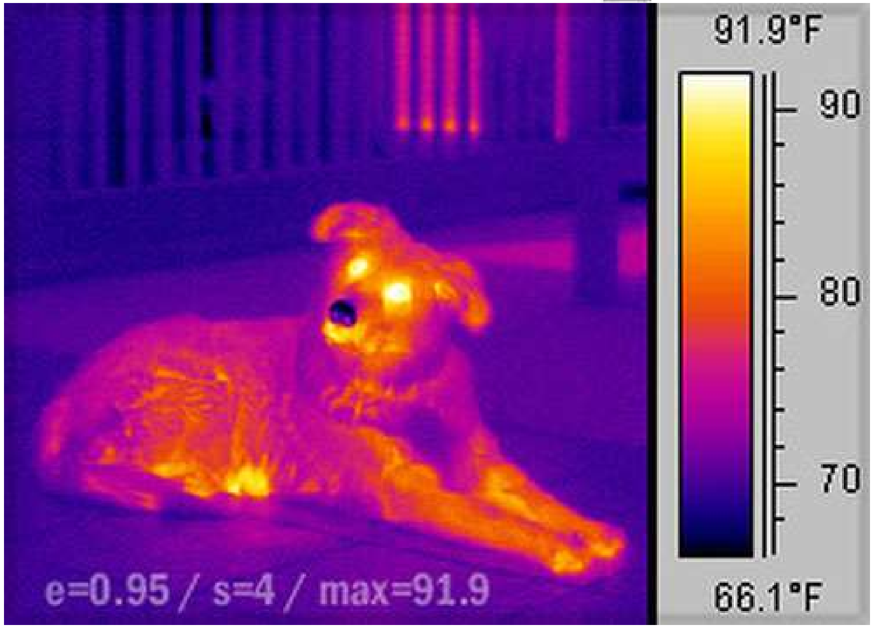




Infrared camera

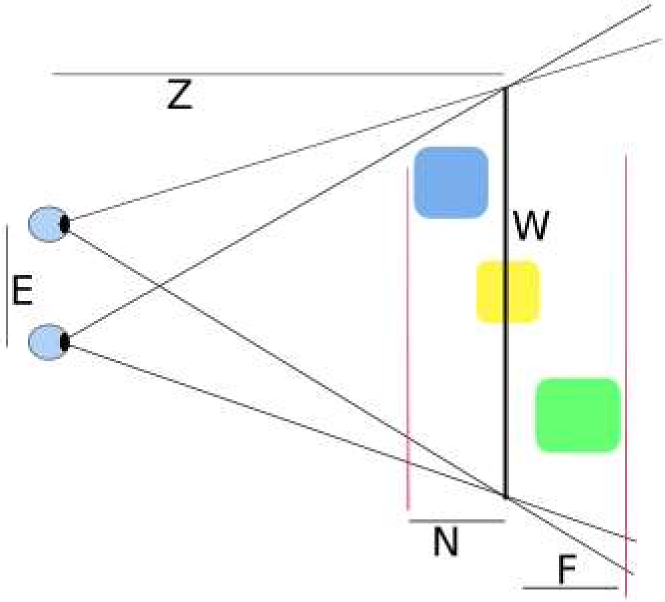
Infrared camera - a device that forms an image using infrared radiation





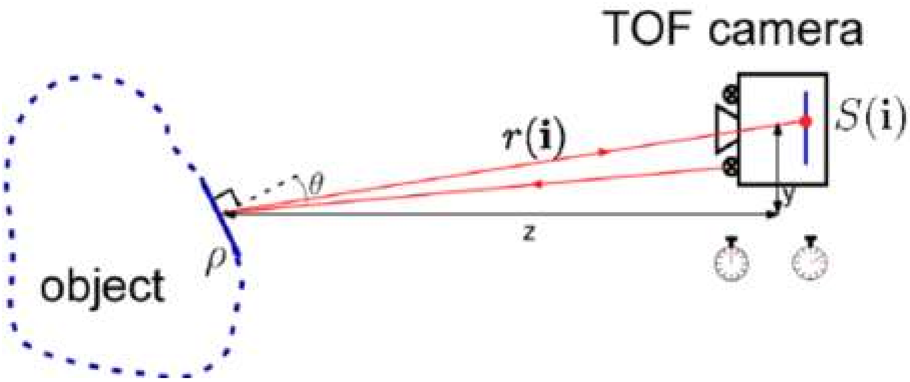
3D (2.5 D) image Acquisition Stereo camera

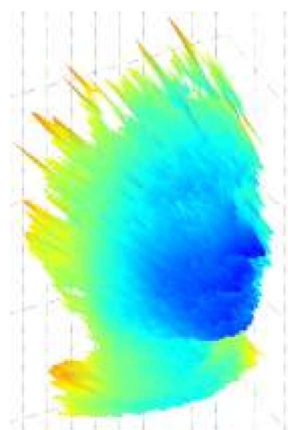
Stereo arrangement



TOF Time-of-flight (2.5 D camera)

- X MHz intensity-modulated light source
- Emitted light is reflected back to the camera by objects or persons within the scene
- Smart pixels in the sensor determine its phase shift for each pixel
- The phase shift is proportional to the distance of the captured object





IR pattern (2.5 D camera)

1. Emit if IR pattern
2. Capture the IR image using CMOS camera with an IR-pass filter
3. Relative position of dots in the pattern – calculate depth displacement at each pixel position