MTA SZTAKI
Hungarian Academy of Sciences
Institute for Computer Science and Control

Imagers and imaging techniques

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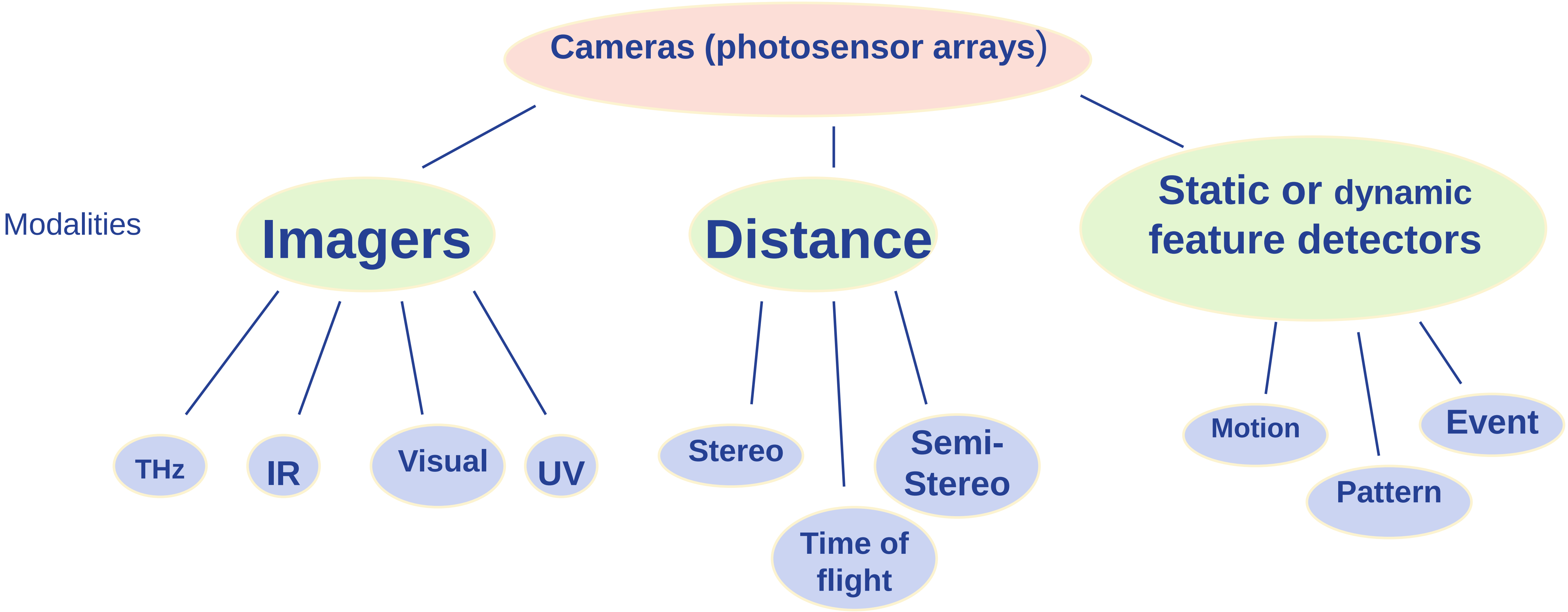
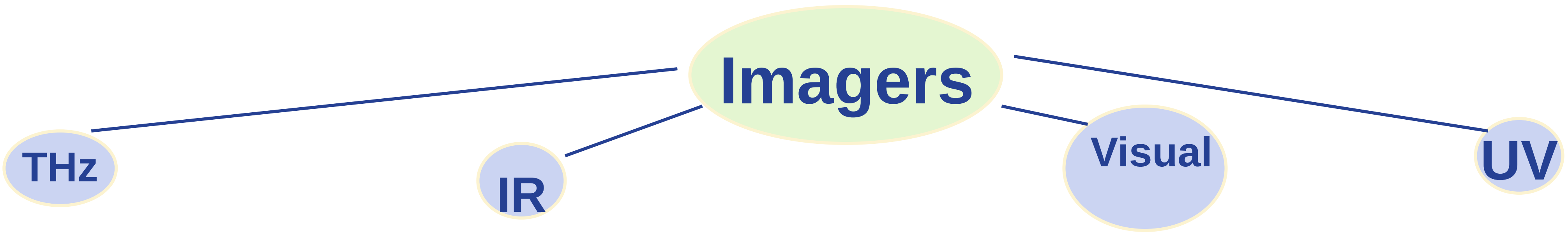
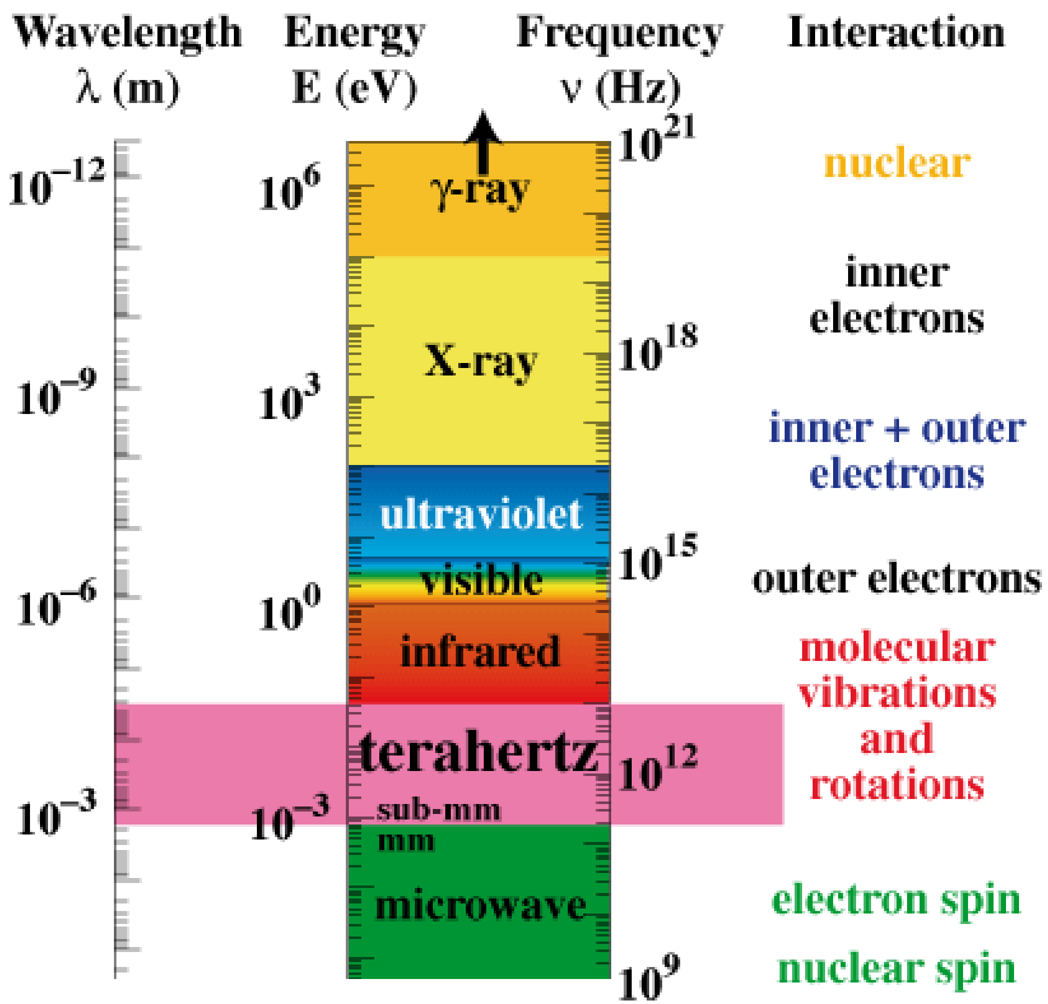
MTA-SZTAKI

SSIP 2016, Szeged
24th Summer School on Image Processing


Cameras (photosensor arrays)
Modalities
Imagers
Distance
Static or dynamic feature detectors
THz
IR
Visual
UV
Stereo
Time of flight
Semi-Stereo
Motion
Pattern
Event


Imagers
THz
IR
Visual
UV

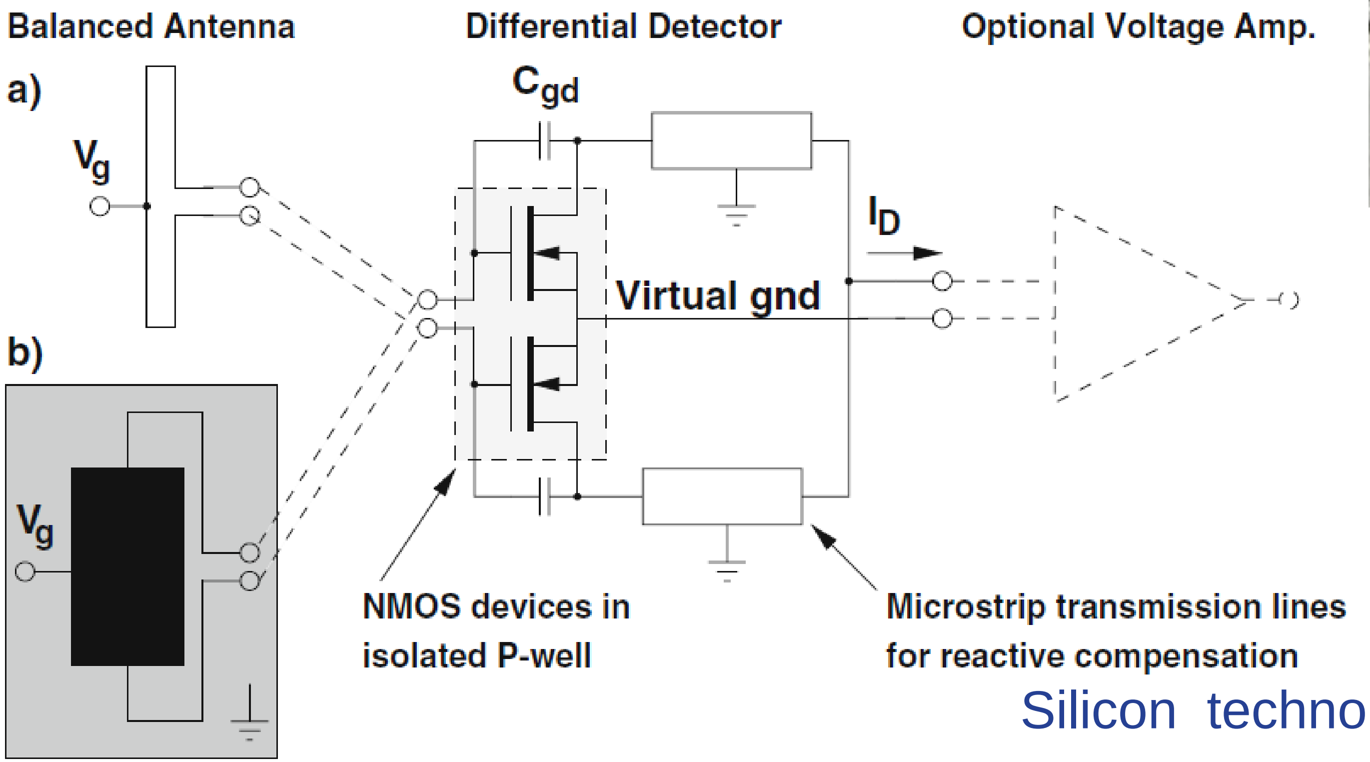

Wavelength
λ (m)
Energy
E (eV)
Frequency
ν (Hz)
Interaction
10^-12
10^-9
10^-6
10^-3
10^6
10^3
10^0
10^-3
10^21
10^18
10^15
10^12
10^9
γ-ray
X-ray
ultraviolet
visible
infrared
terahertz
sub-mm
mm
microwave
nuclear
inner
electrons
inner + outer
electrons
outer electrons
molecular
vibrations
and
rotations
electron spin
nuclear spin

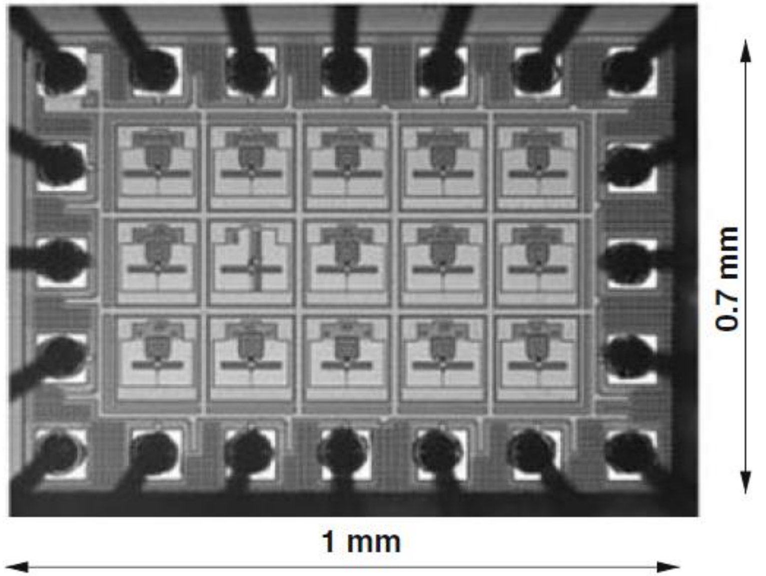
Imagers

THz

IR

- THz Sensors
  - Microbolometer arrays or antenna arrays
  - Sees through cloth and paper
  - Small array or scanning imaging
  - THz illuminators are not powerful and very expensive
  - Terasense: 16x16 – 64 x 64 arrays





Silicon technology

Imagers

THz

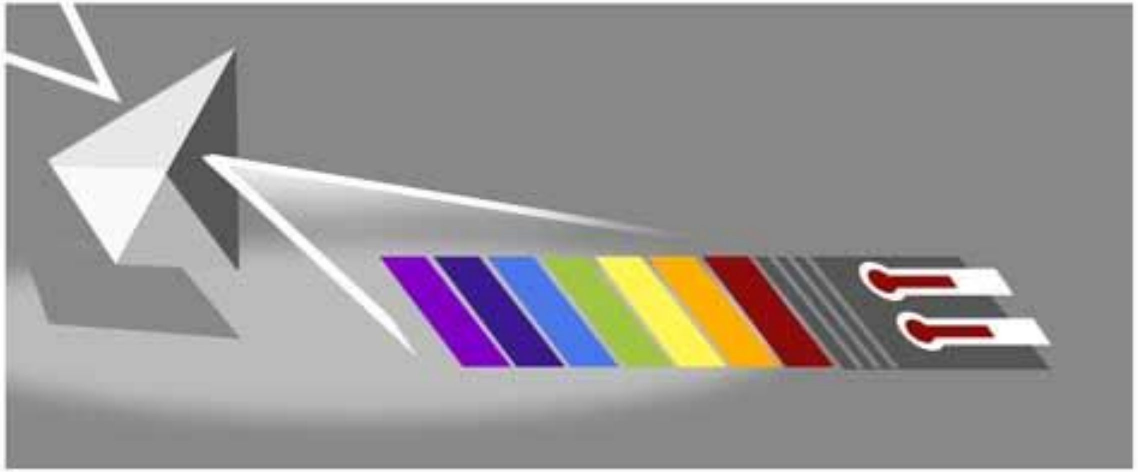
IR

Visual

UV

History

William Herschel' – who actually discovered planet Uranus- experiment (1800)



The temperature of the colors is increasing from violet to red, and even beyond!

Imagers

THz · **IR** · Visual · UV

Near IR (0.8-2μm)

Near infrared	0.8-2μm
Short wave IR (SWIR)	2-5μm
Middle wave IR (MWIR)	5-8μm
Long wave IR (LWIR)	8-12μm

Sees through smoke, fog, plastic

Imagers

THz

IR

UV

Near IR (0.8-$2\mu m$) and SWIR (2-$5\mu m$) sensors

Silicon (below 1 micron)
Cheap CMOS technology

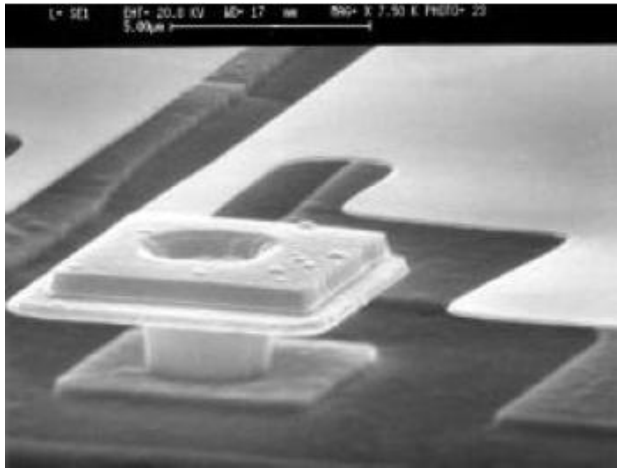
Indium Gallium Arsenide (InGaAs)
(above 1 micron) cooled sensor
Mostly expensive military technology

MWIR (5-$8\mu m$)

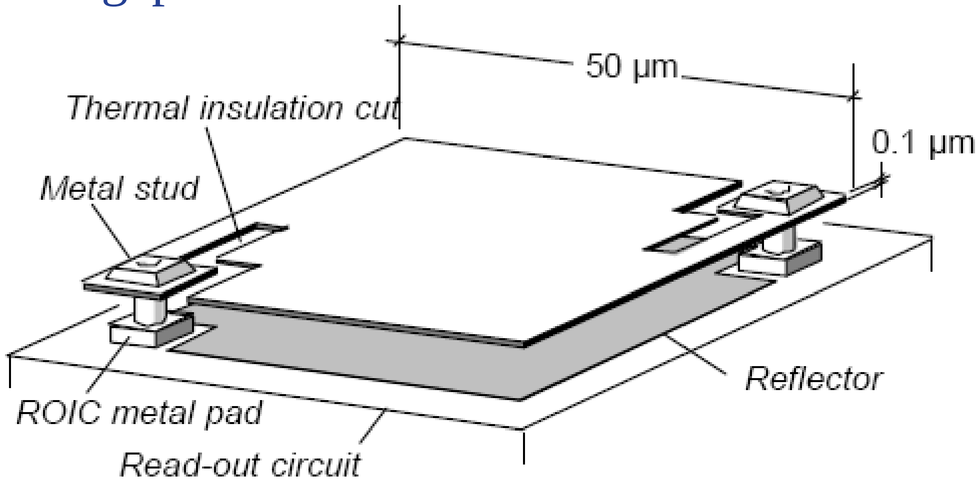
Mercury Cadmium Telluride (HgCdTe) sensor
Cryogenic cooling
expensive military technology

LWIR (8-$12\mu m$)
Microbolometer array

cheap low-end:
80x60 size < $200



high-end : megapixel



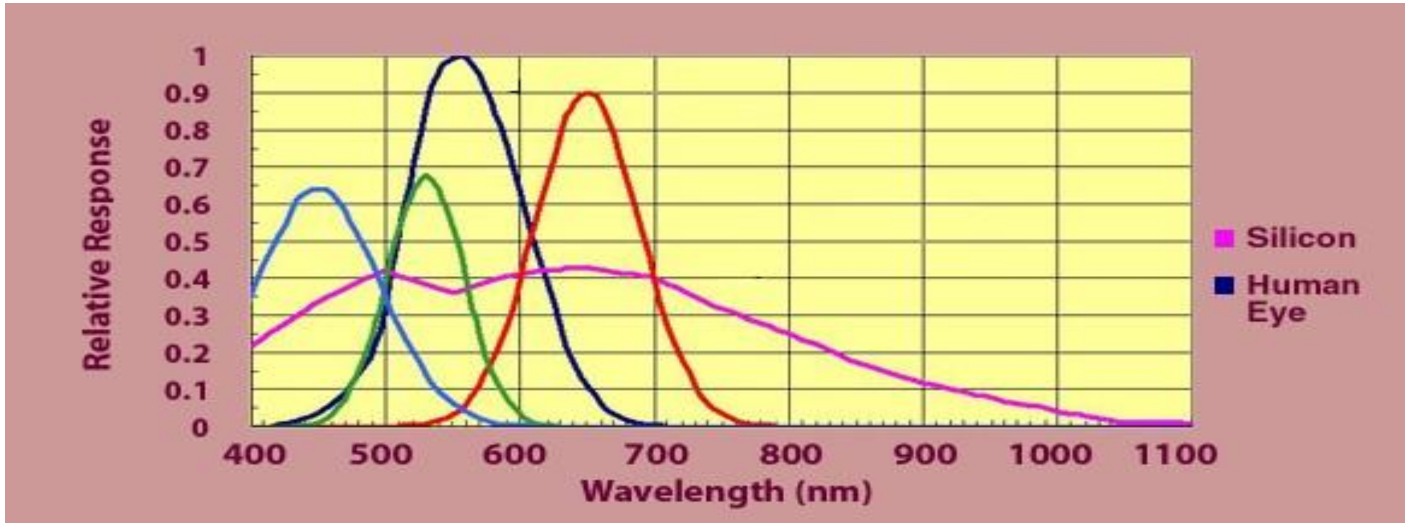
Measurement of the light

- Lumen (*amount of light*):
  - SI derived unit of luminous flux of visual light
  - Unit: 1 lm (lumen)
  - 1 lm = 1 cd·sr = 1 lux·m^2

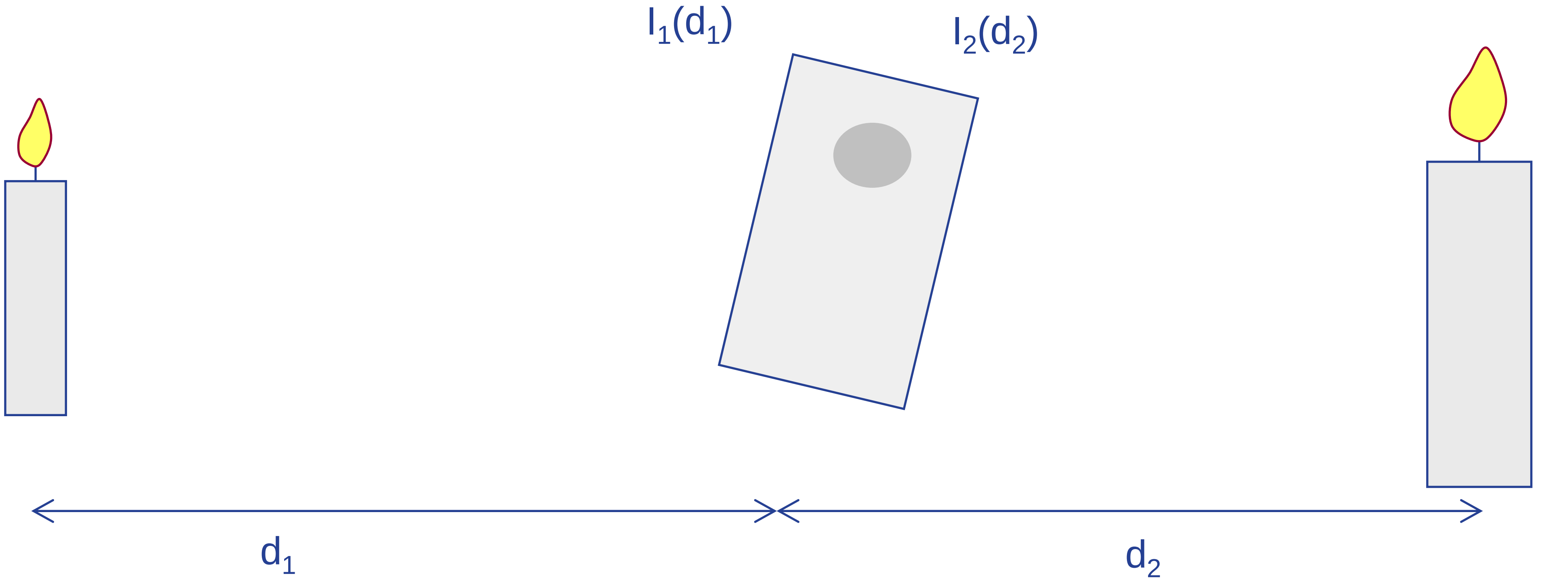
- Candela (*light density in a direction*):
  - SI unit of luminous Intensity
  - Power of the light emitted to a certain space direction in the visual spectrum
  - Unit: 1cd (total light power in the visual spectrum emitted by one candle)

- Lux (*light density on a surface*):
  - SI unit of illuminance and luminous emittance, measuring luminous flux per unit area
  - Wavelength weighted according to human perception
  - Unit: 1 lux (10 lux: a surface is illuminated by a candle from 1 foot distance)

- Weighting (luminosity) function:
  - continuous frequency spectrum
  - our eye can detect a certain range only
  - photopic luminosity function
  - scotopic luminosity function



Experiment: Which light source is more powerful?



$I(d) \sim d^2$

Typical illuminance values

Strong sun on the beach	32,000–100,000 lux
TV studio	1000 lux
Sunrise, sunset (no clouds)	400 lux
Office illuminance	200–400 lux
Home illuminance	50-100 lux
Candle from 30 cm	10 lux
Full moon	0.25 lux
Quarter moon	0.01 lux
Moon less clear night	0.001 lux
Moon less cloudy night	0.0001 lux

Important characteristic numbers of a sensor:

Dynamic range (intra-frame) (human eye: ~80dB, 1:10,000)

Total dynamic range (inter-frame) (human eye : ~120dB, 1:1,000,000)

Imagers

THz IR **Visual** UV

CCD: Charge coupled device

- Introduction: 1974 Bell Laboratory
- Minority of the professional and industrial cameras contains CCDs
  - Point and shoot cameras, video cameras, mobile phone cameras, web cameras are not CCDs any more
- Applications:
  - Video cameras (professional)
  - Industrial cameras (global shutter, low noise)
  - Astrological cameras (high sensitivity, low noise)
- Silicon technology is not compatible with CMOS technology
  - No additional devices (e.g. AD converter, special amplifiers, digital circuits can be integrated to the same chip → analog video signal output)

CMOS: Complementary metal–oxide–semiconductor

- Theory known from the ’60-s:

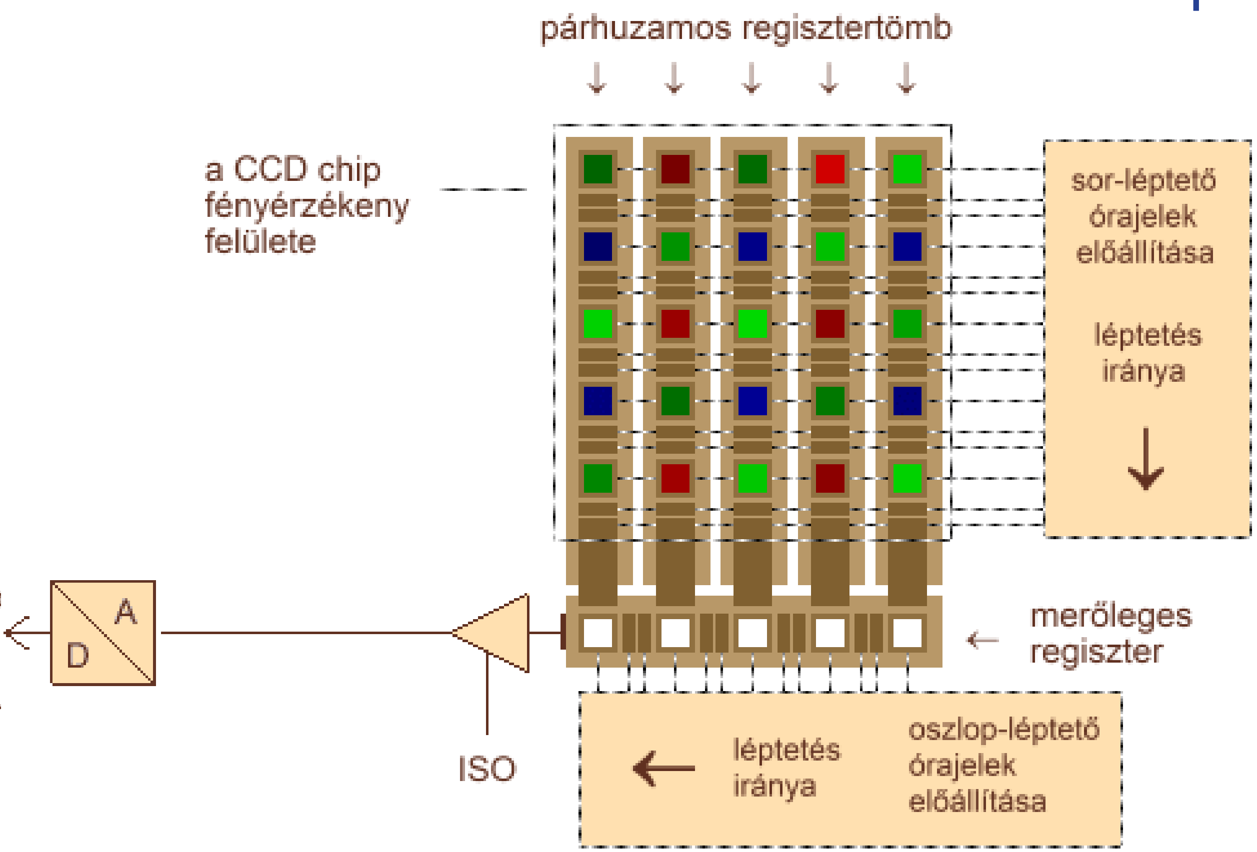
  - photodiode (photon to electron conversion on silicon)
- NASA Jet Propulsion Laboratory
  - First commercial CMOS sensor was made in 1993
- Winning competitor against CCD
  - Suitability depends of the application area
- Application areas
  - Smart phones,
  - Cameras,
  - Industrial camera
- CMOS circuits can be implemented on the same chip
  - ADCs and even Microcomputers next to the sensor

Imagers

THz IR **Visual** UV

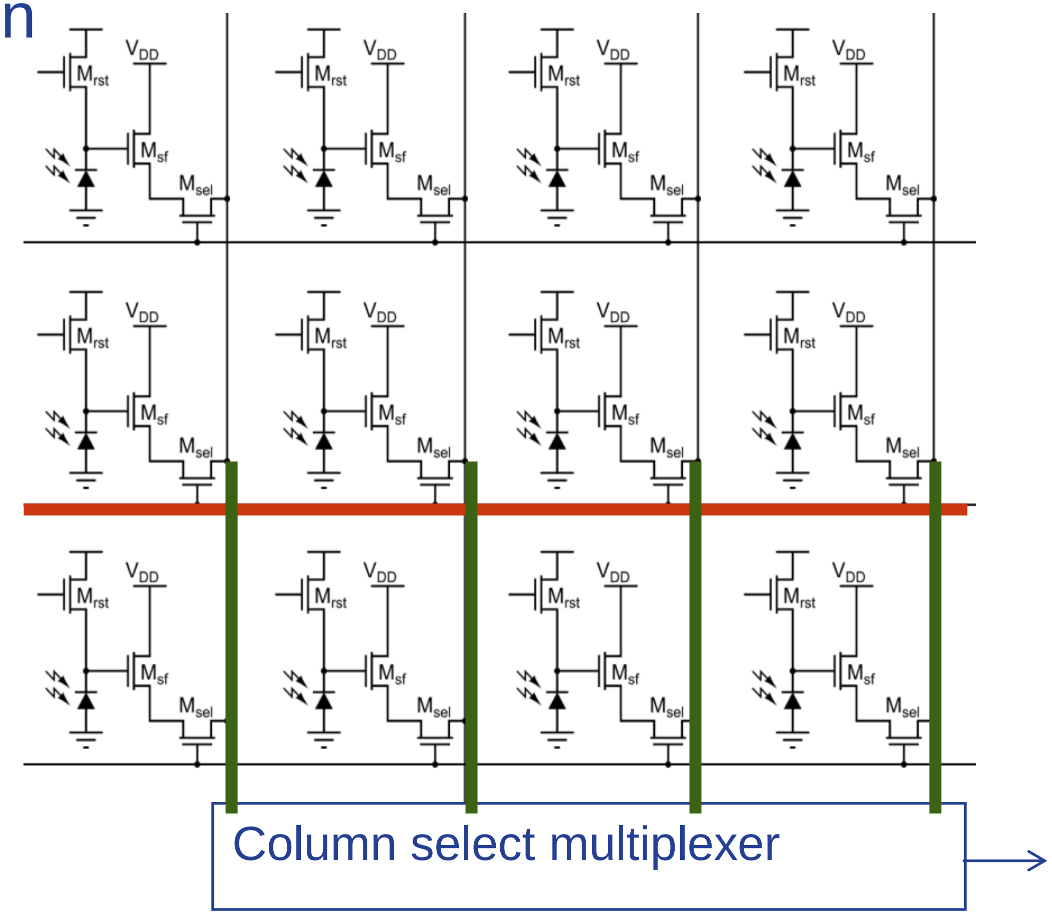
Operation

CCD



Row-wise readout (entire image)

CMOS



Random access readout:
fast ROI readout

Imagers

THz | IR | Visual | UV

Sizes and dynamic range

CCD

- Spatial and temporal resolution:
  - 762x526 video camera 30 Hz (PAL)
  - 1980x1024 HD camera 60Hz
  - 1280x1024 industrial camera 15 Hz
  - 3000x4000 digital camera 1 Hz
  - 12000x12000 military, space, and astronomical application 0.1 Hz
- CCD pixel clock:
  - 40 MHz (8-10 bit resolution)
  - 10MHz (12 bit resolution)
  - 1MHz (16 bit resolution) COOLED!

CMOS

- Spatial resolution
  - From 128x128 up to 25,000x25,000
- Pixel clock: 20-160 Mpixel/sec
- Windowing (region of interest: ROI)
  - Frame-rate is proportional with window area
- Frame-rate (temporal resolution)
  - 15-1000 FPS (without windowing)
  - Up to 10,000 with ROI
- Accuracy (linear integrating) 8-10 bits
  - 8-10 bits (linear integrating type)
  - Up 20 bits HDR (multi-exposure or tri-linear)

Noise floor

Typical	CCD (CCD47-10, e2V)	Linear CMOS (IBIS5)
How many electrons fit maximum to one pixel? [e^-]	100 000	50 000
Dark current @ 20Celsius [e^-/s]	115 (average)	410 (average)
How many degrees increase needed to double the dark current?	4	8
LSB: how many electrons?	2	35
Full dynamic range (intra-frame)	50 000:1	1 600:1
Quantum efficiency	80%	30%
1000 photons	800 e^- (400LSB)	300 e^- (8LSB)

Maximum integration time (error < 10%)

Temperature	CCD (CCD47-10, e2V)	CMOS (IBIS5)
-40C	200 000s (51 hours)	1810s
-20C	10 000s	320s
0C	900s	56s
20C	85s	10s
40C	8s	1.8s

Astronomical application

Rolling Shutter vs Global Shutter

most CMOS sensors | **all CCD and some CMOS sensors**

- Rolling shutter causes problem when either the camera or the object moves
- http://www.diyphotography.net/everything-you-wanted-to-know-about-rolling-shutter/

beginning of the frame

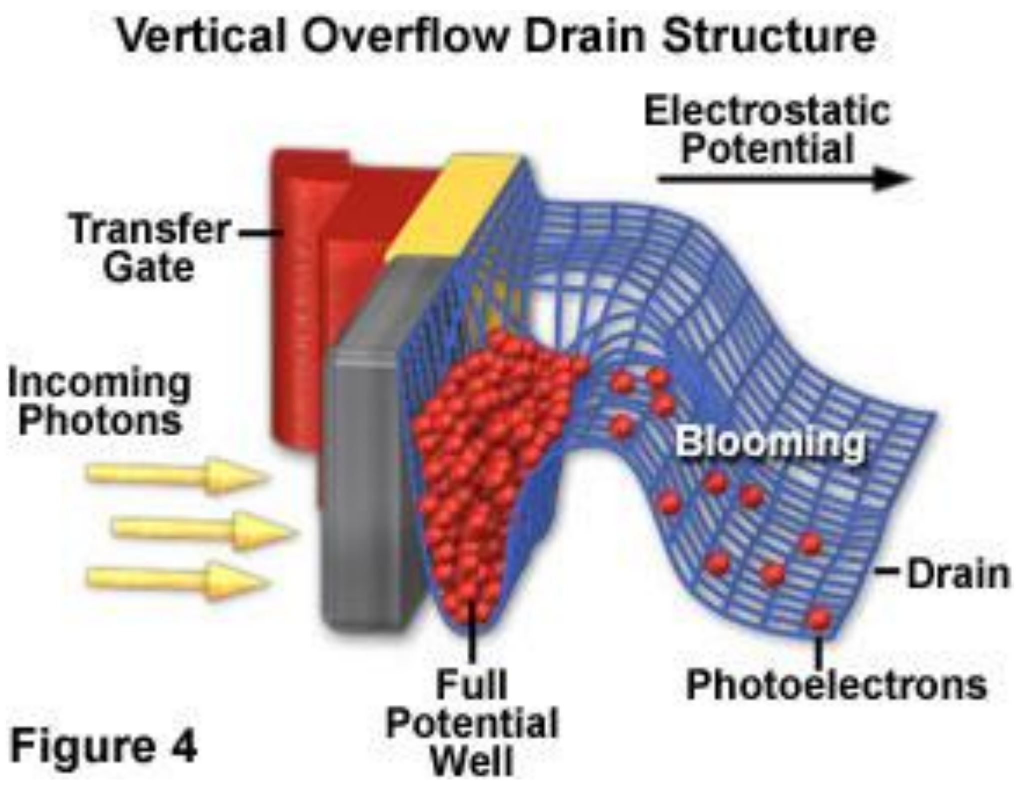
end of the frame

captured image

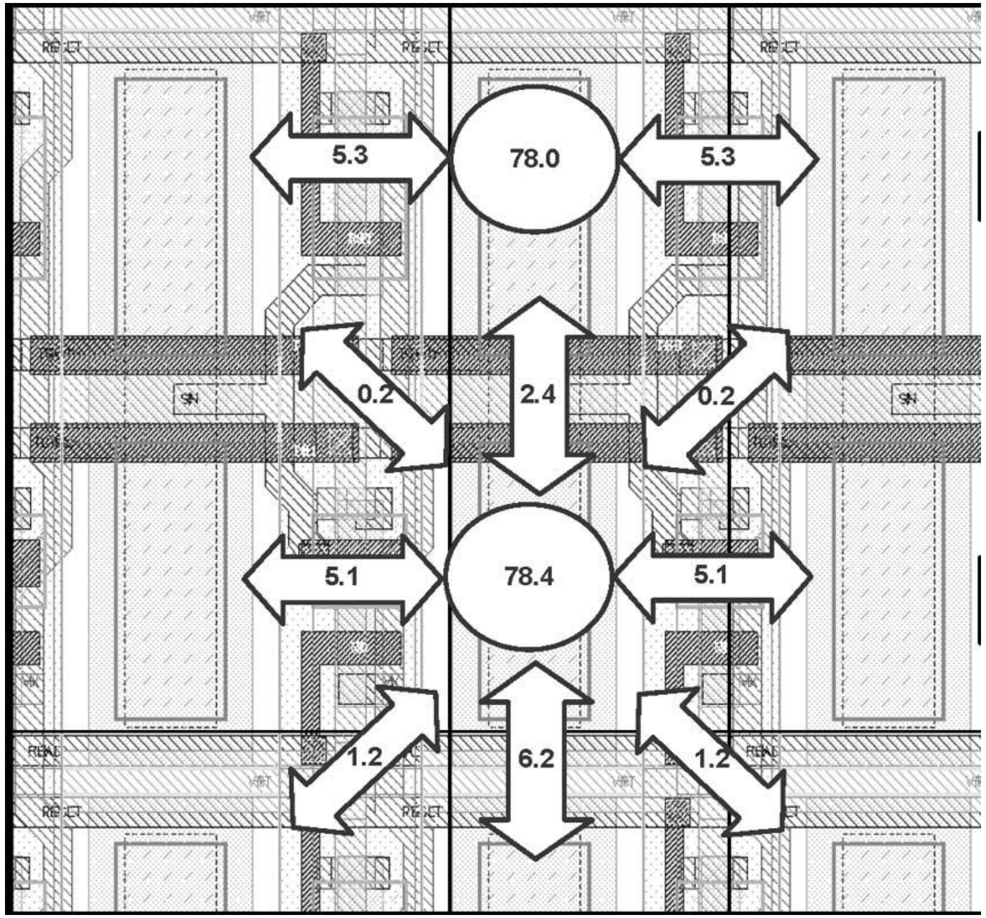
Overflow

CCD: blooming and smearing

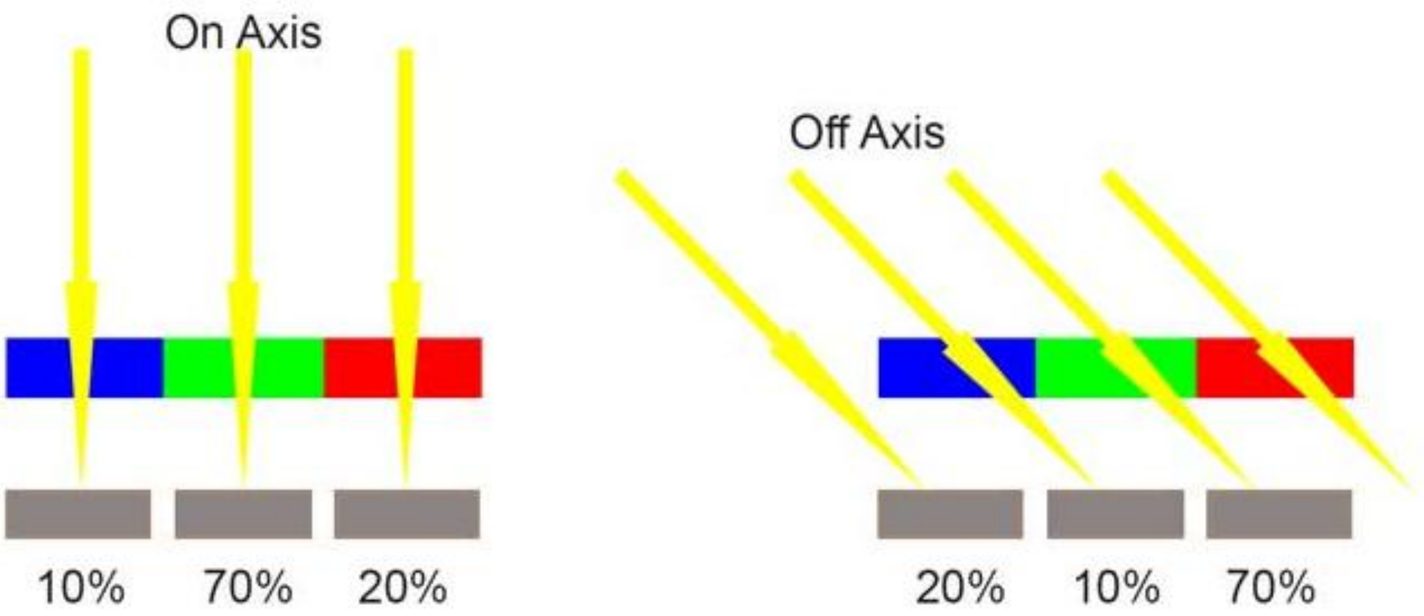
CMOS: blooming and smearing



Cross-talk



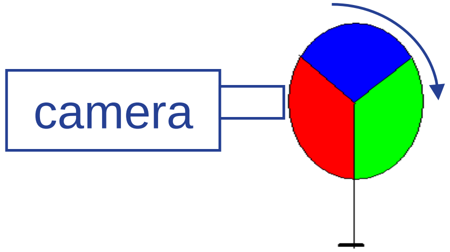
Cross talk can be up to 20%



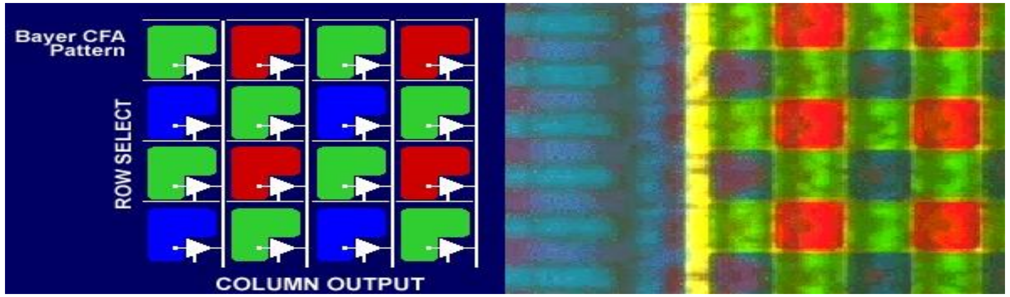
Spatial dependency of cross-talk depends on the chief ray angle

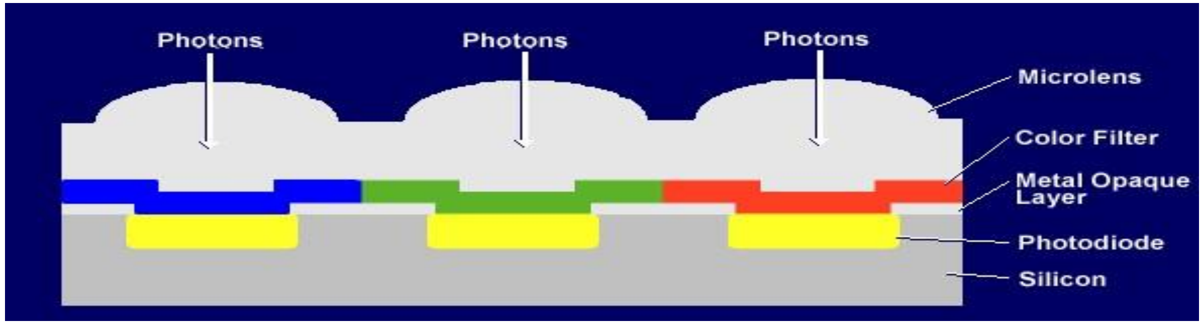
Color sensing techniques – separation of color channels

- Separation in time:
  - Synchronized color wheel

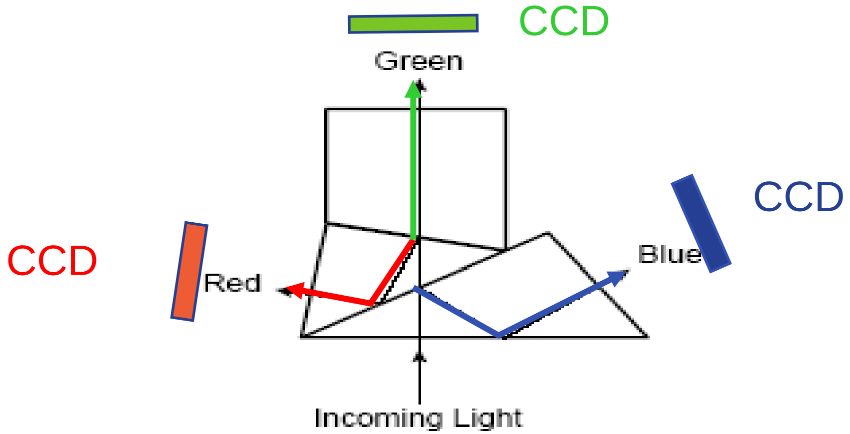


- Separation in space I
  - Bayern pattern
  - typical solution today



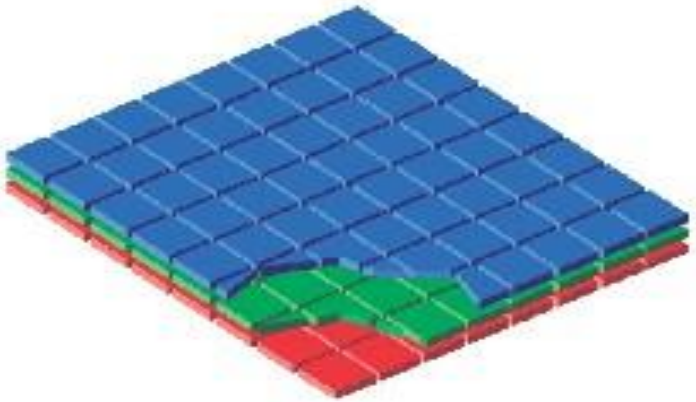


- Separation in space II
  - High-end solution
  - Increasing sensor number
  - 3 CCD camera (3 chip camera)

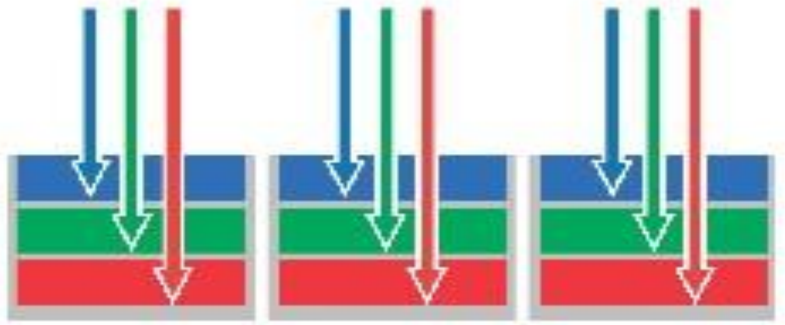


Color image interpolation Bayern patterns

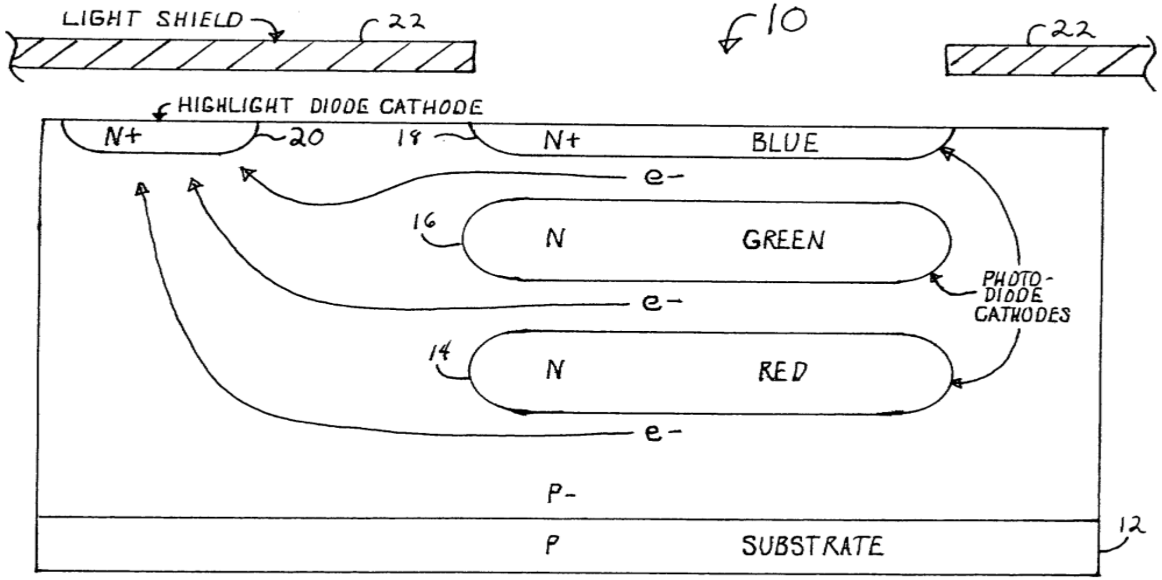
New way of color sensing: Foveon



the vertical color filter features three separate layers of photodetectors embedded in silicon



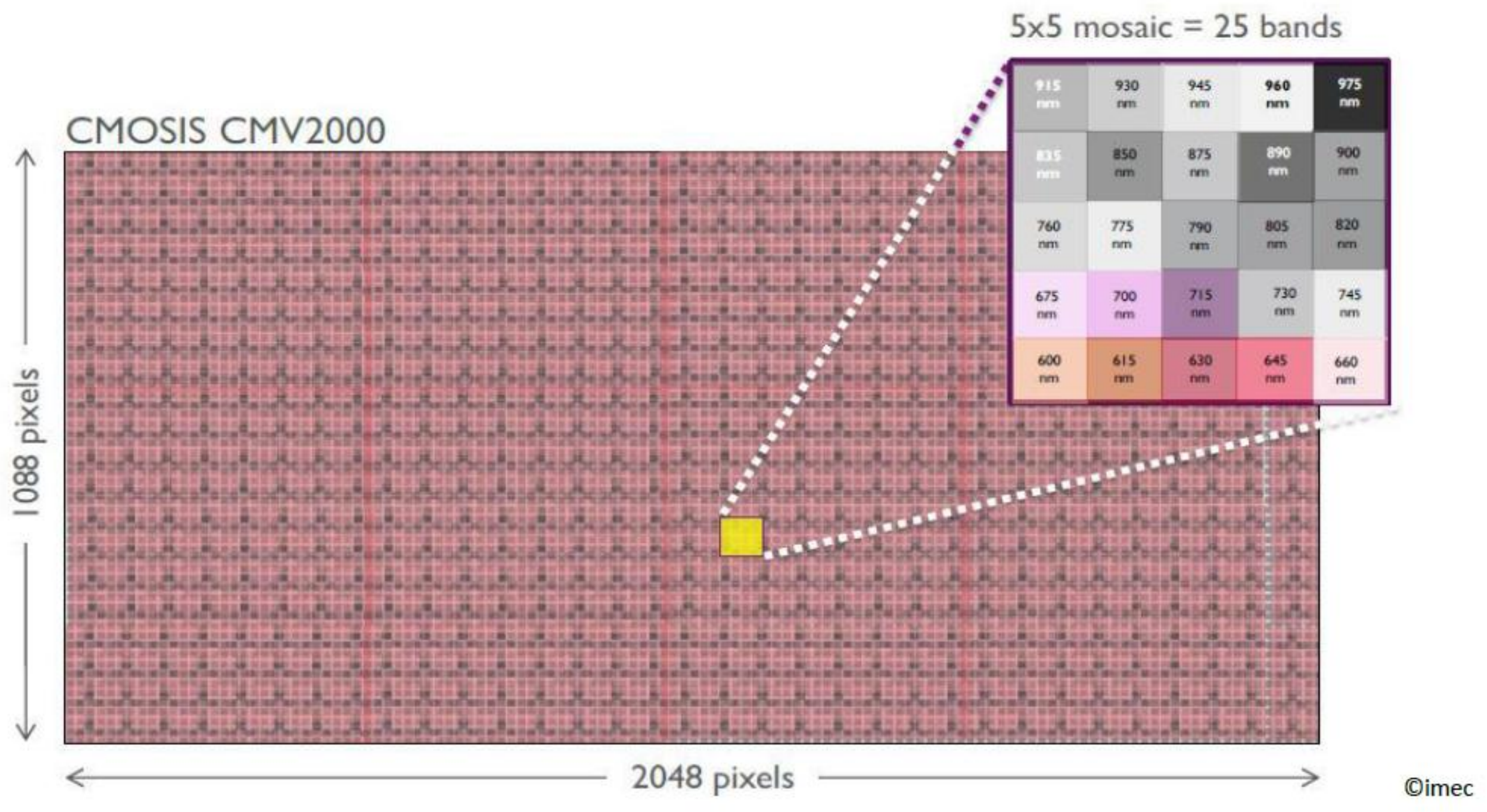
because silicon absorbs different wavelengths of light at different depths, each layer captures a different color



This sensor (made by Foveaon) is on the market, and can be found in digital cameras.

Hyperspectral camera with 5x5 “Bayern pattern”

SNAPSHOT MOSAIC HSI Sensor design, XIMEA camera MQ022HG-IM-SM5X5-600-100(



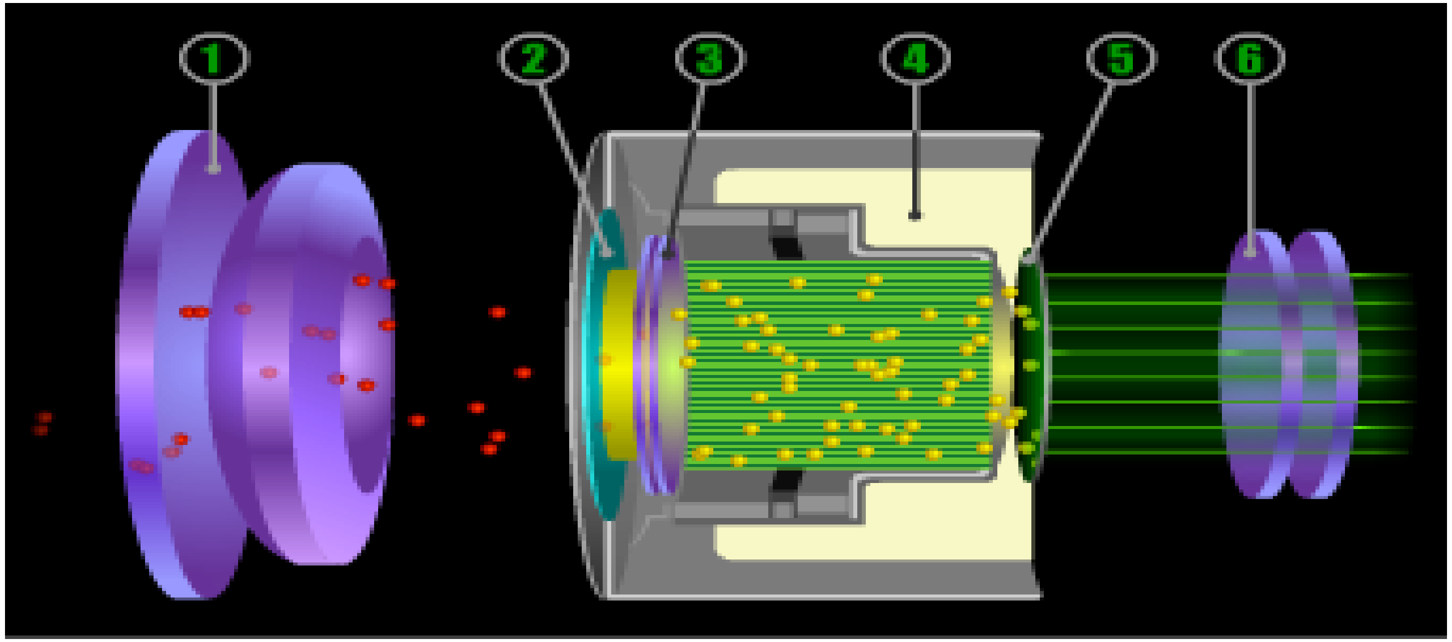
Key specification

Spectral resolution:	5x5 mosaic = 25 bands in 600-975nm
FWHM:	~ 16nm
Spatial resolution:	from 409x217 (per band) ⍰ up to 2Mpx (per band) depending on demosaicing algorithm
Speed:	up to 170 data-cubes / s (full sensor frame)

Image intensifiers

- 50,000 times gain
- Daytime: nanosec gating
  - (range measurement)
- ~1 megapixeles resolution

Modern image intensifier tube



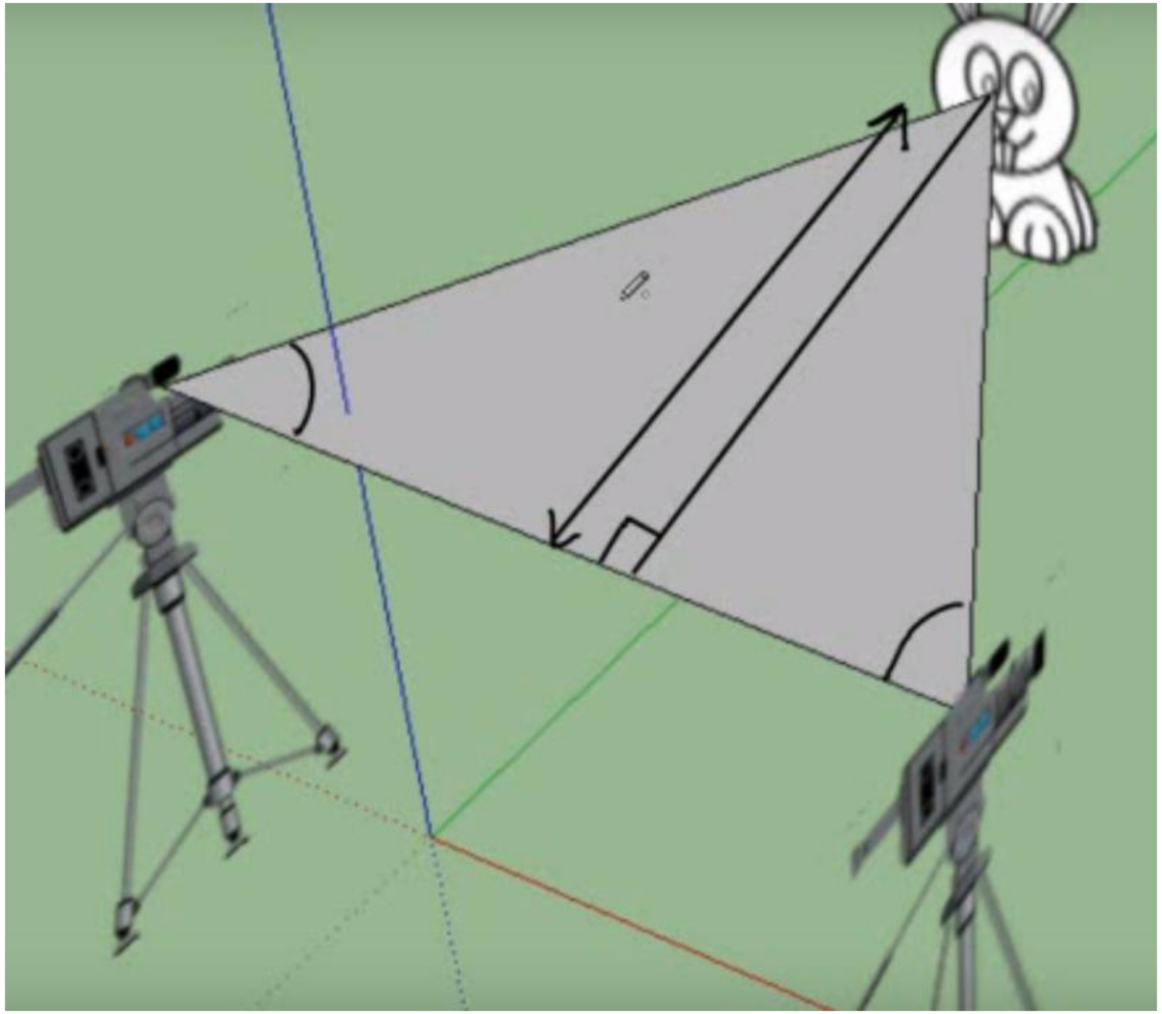
1. Front Lens
2. Photocathode
3. Microchannel plate
4. High Voltage Power Supply
5. Phosphorus Screen
6. Eyepiece

Distance sensor

Stereo

Semi-Stereo

Time of flight



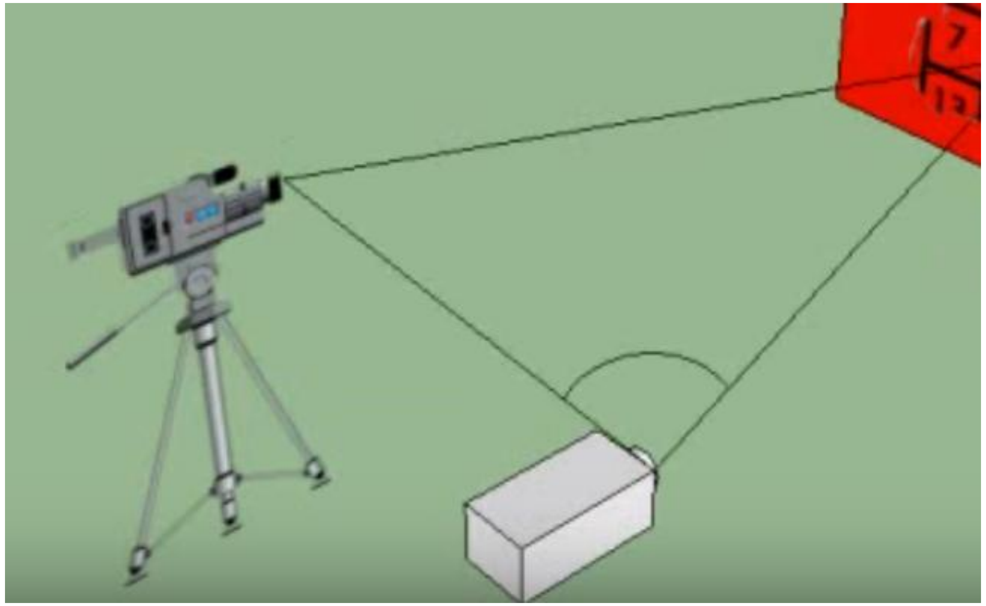
- Uses two cameras
- Identifies marker points pairs
- With known geometry, the disparity of a marker point pair tells the distance
- Problems: the marker point pairs are ambiguous

Distance sensor

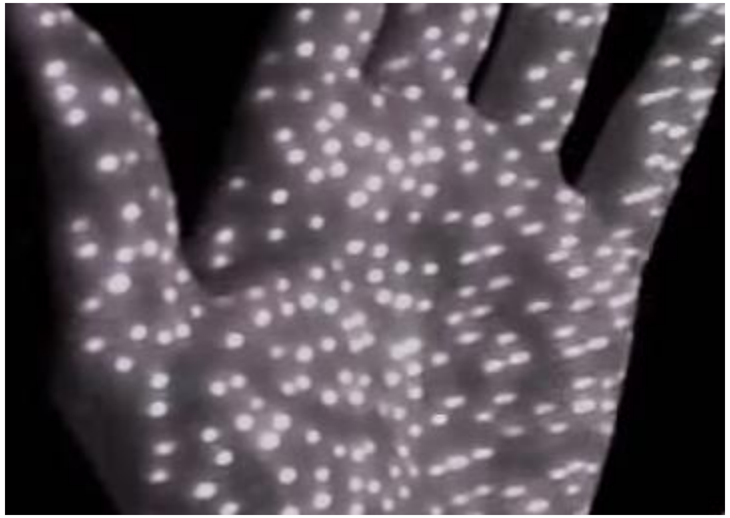
Stereo

Semi-Stereo

Time of flight



- Semi-Stereo – like Kinect – uses one camera and a pattern projector
- Camera should identify the pattern, and the angle tells the distance



Random speckle pattern

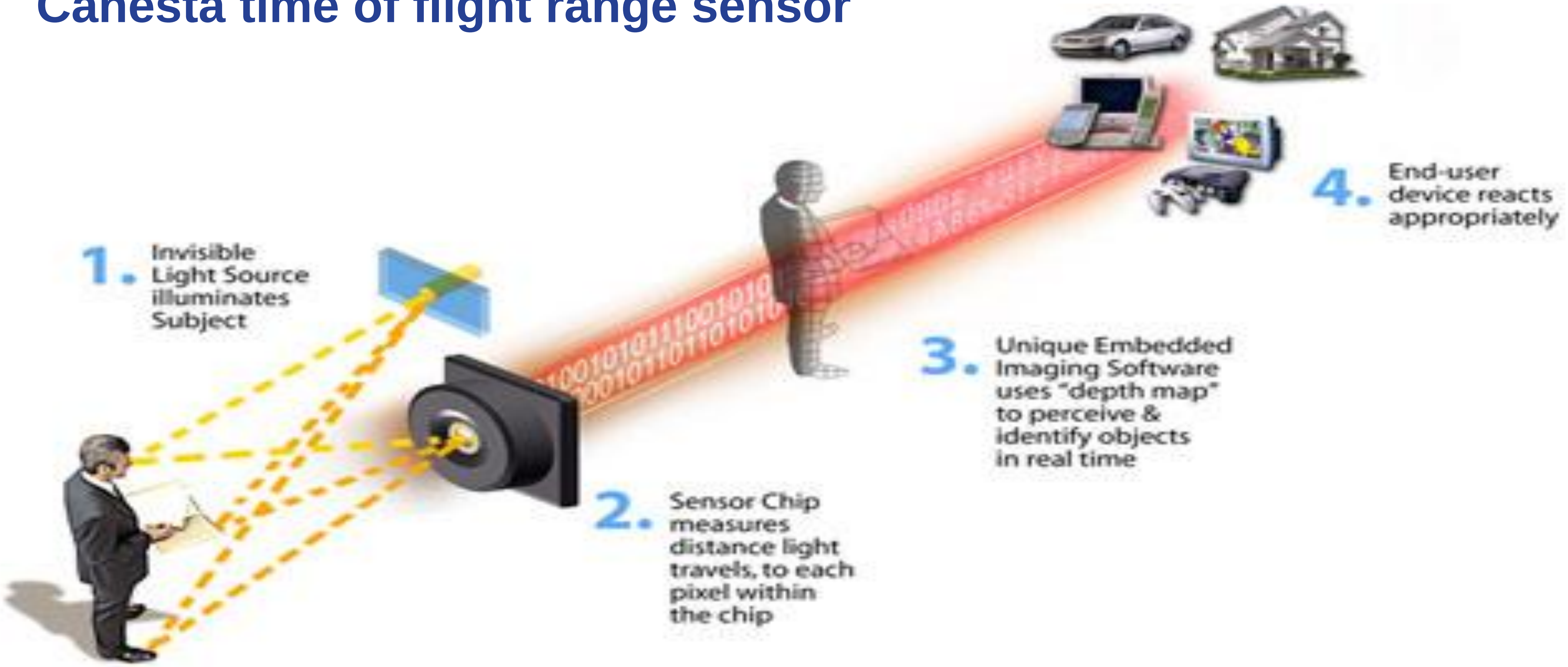
Distance sensor

Stereo

Semi-Stereo

Time of flight

Canesta time of flight range sensor



Canesta range sensor array

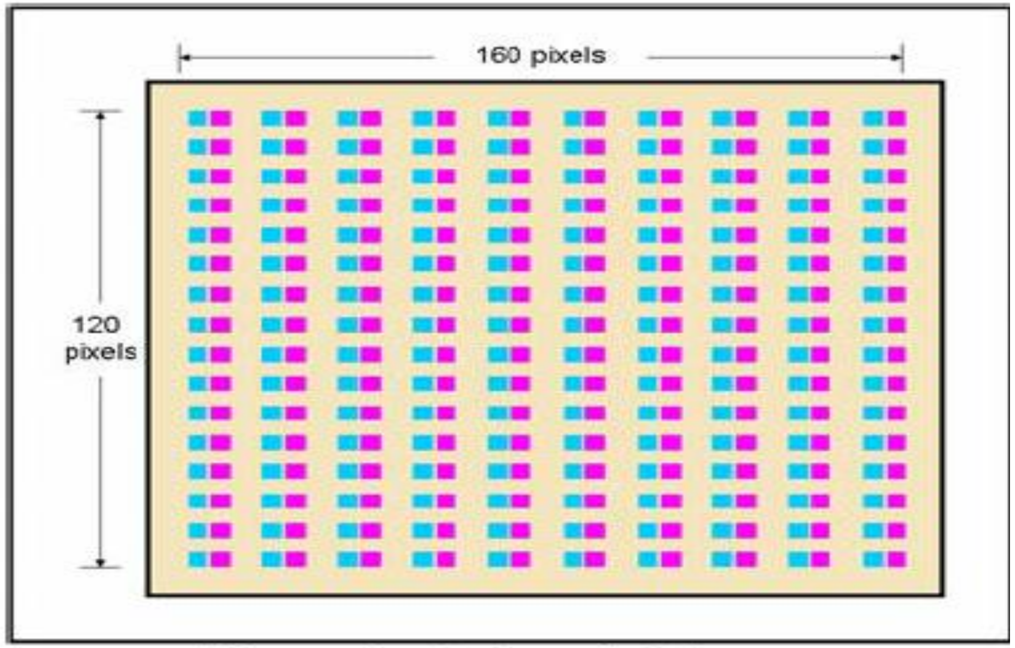


Figure 2 - Industrial Sensor

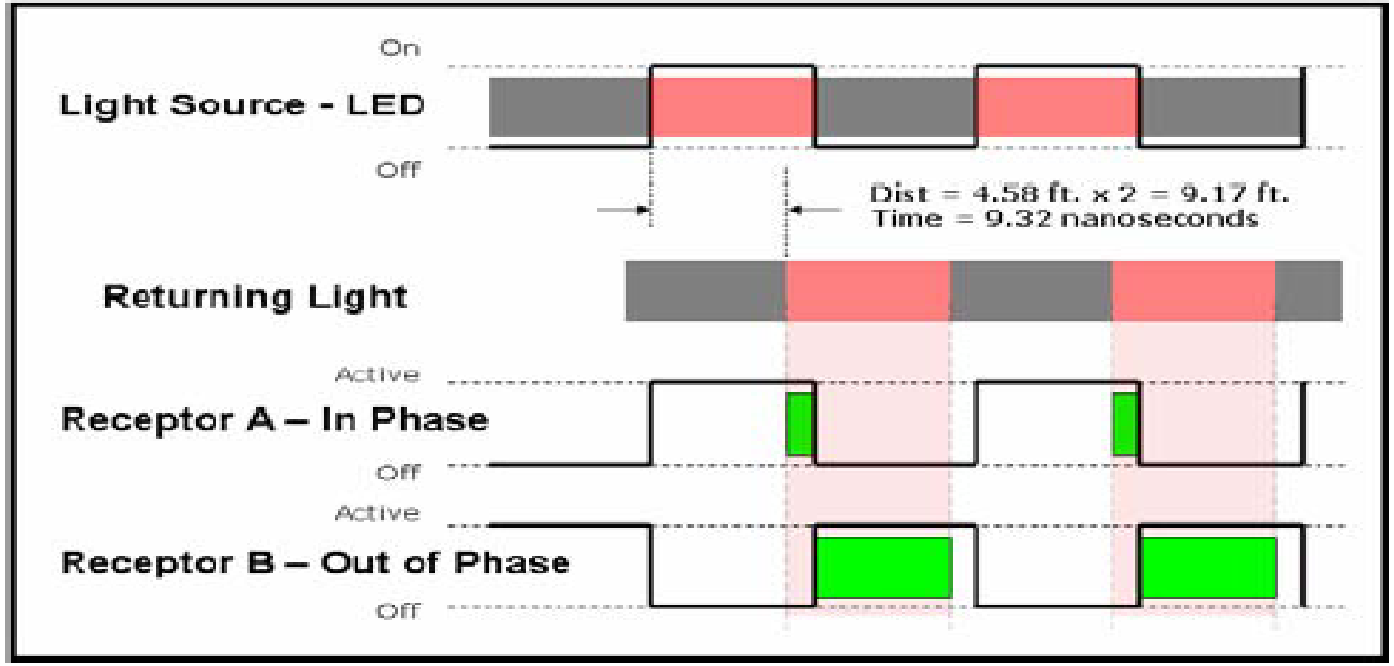


Figure 14 - Timing of Light Reflecting to Receptors

- 160x120 array
- Every pixel contains two photodetectors
- There is a two phase light source
- Detectors are switched on and off syncronized with the illuminator

Thank you for your attention!
Questions?

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