Machine vision

Lecture 3
Machine perception and visual sensors

Visual perception

- Geometric properties, in terms:
  - Posture,
  - Motion,
  - Shape,
- Appearance, in terms:
  - Chrominance (color),
  - Luminance (intensity),
  - Texture (specific and regular distribution of chrominance and/or luminance)

Machine vision

- Computer vision
  - To recover useful information about a scene from its 2-D projections.
  - To take images as inputs and produce other types of outputs (object shape, object contour, etc.)
  - To create a model of the real world from images
  - Geometry + Measurement + Interpretation.

Information processing in visual perception

- Image processing
  - To detect the uniformity, continuity, discontinuity of the chrominance, luminance, texture
  - Image transformation
  - Image filtering
- Feature extraction
- Geometry measurement
- Object recognition
- Image understanding
- Knowledge representation

Vision system hardware

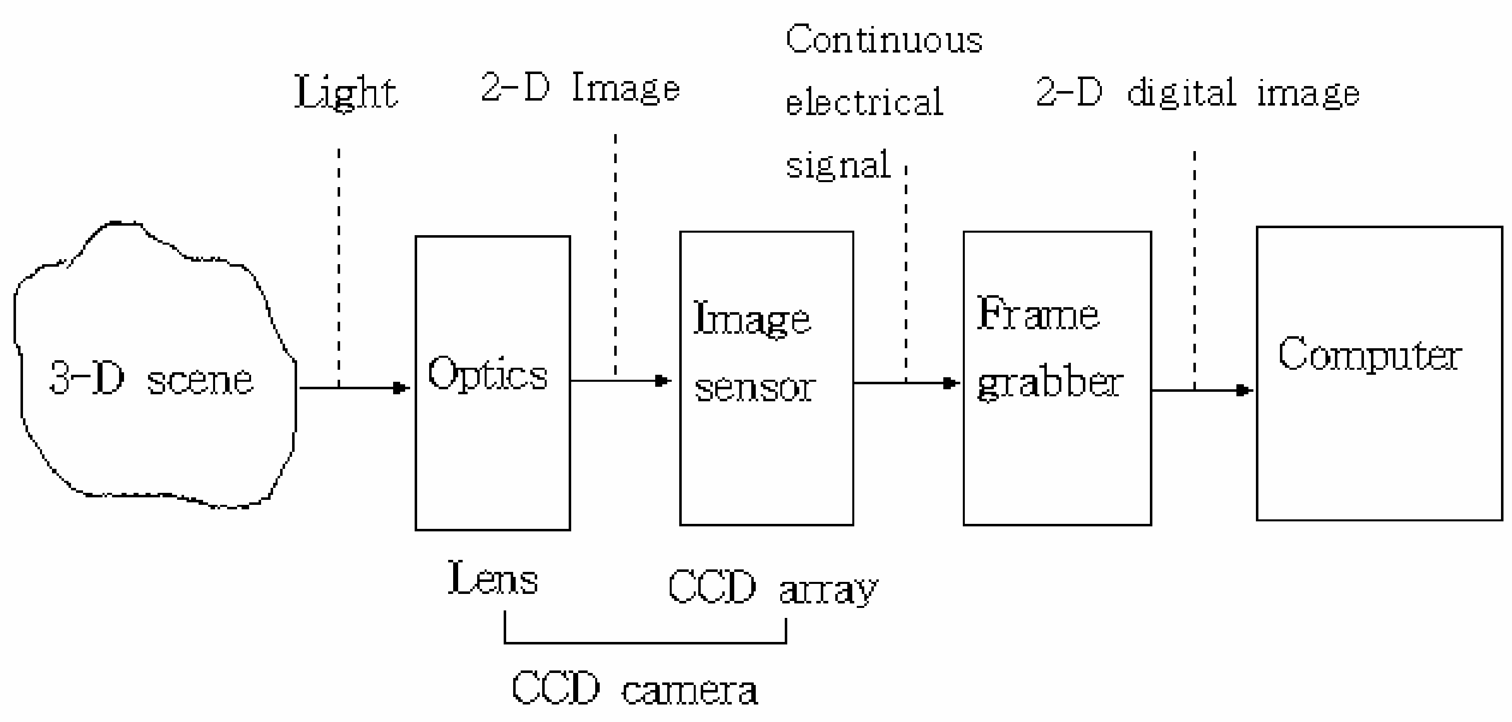


Image Representation

- Images are usually represented by a 2-D intensity function f(x,y) where
  - x and y represent spatial coordinates
  - The value of *f* is proportional to the brightness (gray level) of the image.
- A digital image u(m,n) is represented by a matrix whose rows and columns identify a point in an image and matrix element value identifies the gray level at that point.
- Each point is referred to as a picture element or “pixel”

Image

- Image : a two-dimensional array of pixels
- The indices [i, j] of pixels : integer values that specify the rows and columns in pixel values

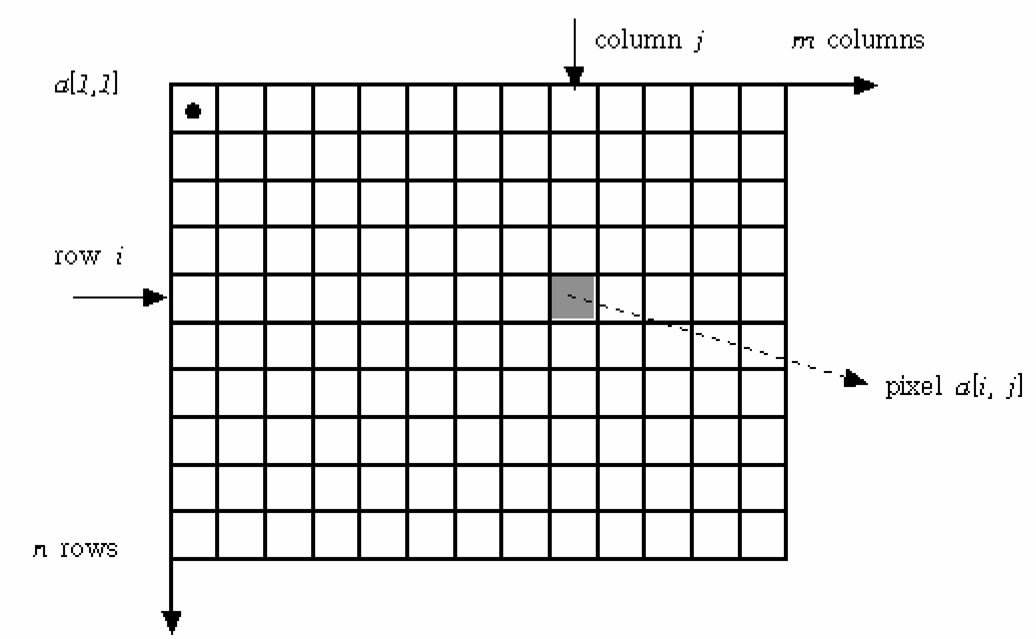
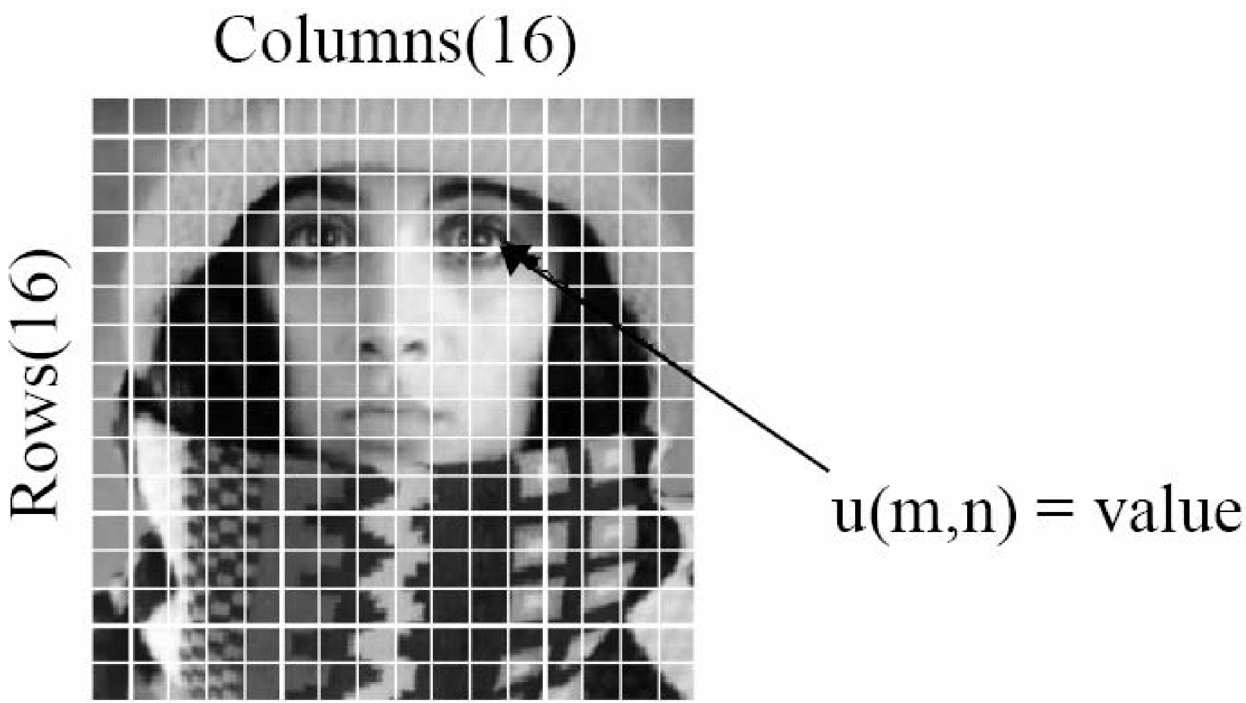


Image representation

For computer storage, an array with the number of gray levels being a power of 2 is selected.

A typical gray level image contains 256 shades of gray (8 bit)

Values are stored between 0 - 255



Sampling, pixeling and quantization

- Sampling
  - The real image is sampled at a finite number of points.
  - Sampling rate : image resolution
    - how many pixels the digital image will have
    - e.g.) 640 x 480, 320 x 240, etc.
- Pixel
  - Each image sample
  - At the sample point, an integer value of the image intensity

- Quantization
  - Each sample is represented with the finite word size of the computer.
  - How many intensity levels can be used to represent the intensity value at each sample point.
  - e.g.) $2^8 = 256$, $2^5 = 32$, etc.

Transformation of color image (RGB) to intensity image representation

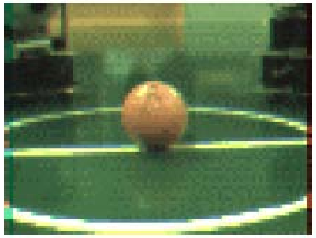
- *I(I,j) = 0.3 x r(I,j) + 0.59 x g(I,j) + 0.11 x b(I,j)*
- *Where r – red, g – green, b – blue*
- *I,j – coordinates of pixel*

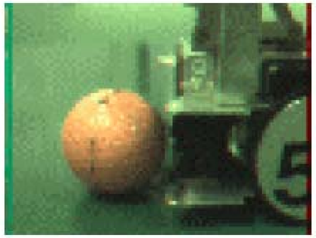
Digital Cameras

"In 1995 cameras for embedded systems were unthinkable.
That's why I developed one!"

Today they are commonplace:

- Digital cameras
- PDAs with cameras
- Gameboy with camera
- Digital surveillance cameras with on-board processing





Bräunl 2004

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Digital Cameras

- Technology
  - CCD (charge coupled devices)
  - CMOS (complementary metal oxide semiconductor)

- Resolution
  - 60x80 black/white up to
  - several Mega-Pixels in 32bit color

However: Embedded system has to have computing power to deal with this large amount of data!

Vision (camera + framegrabber)

Digital Cameras

State of the Art for Embedded Controllers
("Embedded Systems" Industrial Fair, Nurnberg 2001)

- Embedded PC (incl. ethernet, frame grabber, color LCD, CAN bus, 5/12V) up to **800 MHz**
- Systems with extended temperature range up to **266 MHz**
- Systems with ext. temp. and electromagnetic pulse compatibility up to **133 MHz**
- Disk on chip (solid state disks) up to **128 MB**
- Systems on chip - custom solutions (e.g. incorporating ARM proc. kernel) feasibility study, $100,000 - production setup up to $1,000,000

- Performance of embedded system: 10% - 50% of standard PC

Interfacing Digital Cameras to CPU

- Interfacing to CPU:
  - Completely depends on sensor chip specs
  - Many sensors provide several different interfacing protocols
    - versatile in hardware design
    - software gets **very complicated**
  - Typically: 8 bit parallel (or 4, 16, serial)
  - Numerous control signals required

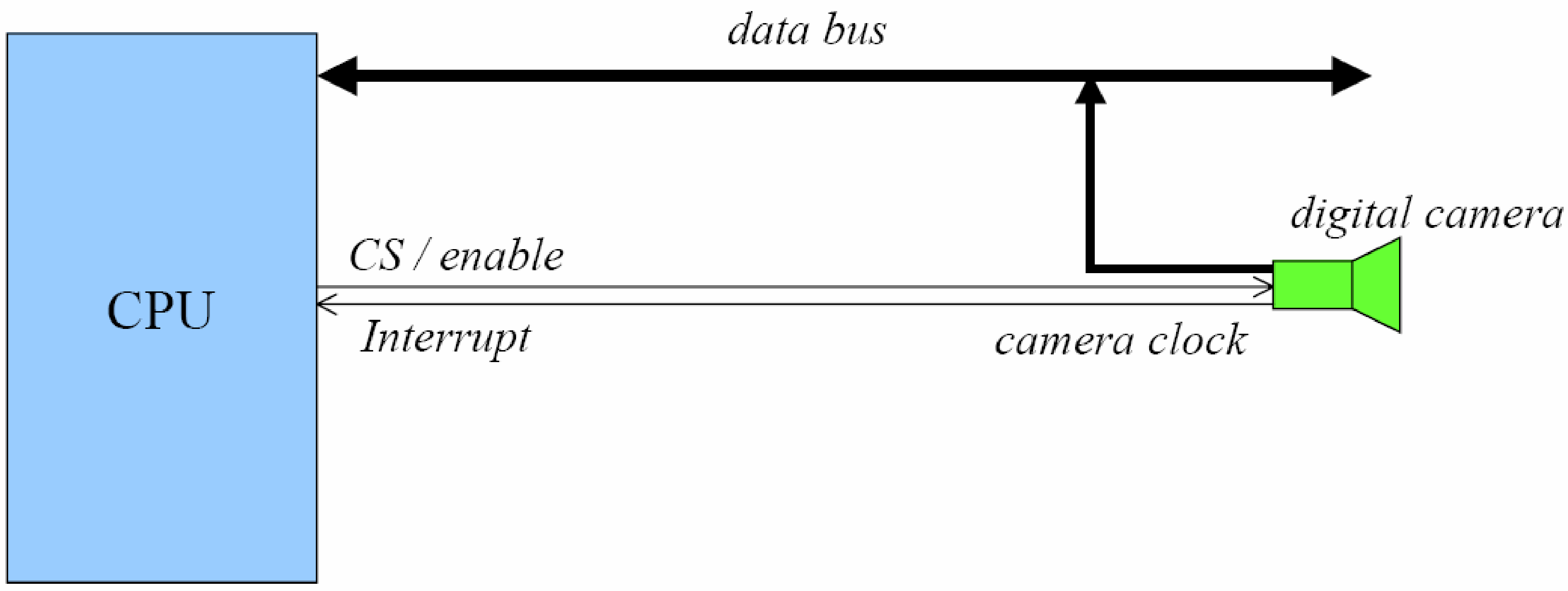
Interfacing Digital Cameras to CPU

- Digital camera sensors are very complex units.
  - In many respects they are themselves similar to an embedded controller chip.

- Some sensors buffer camera data and allow slow reading via **handshake** (ideal for slow microprocessors)

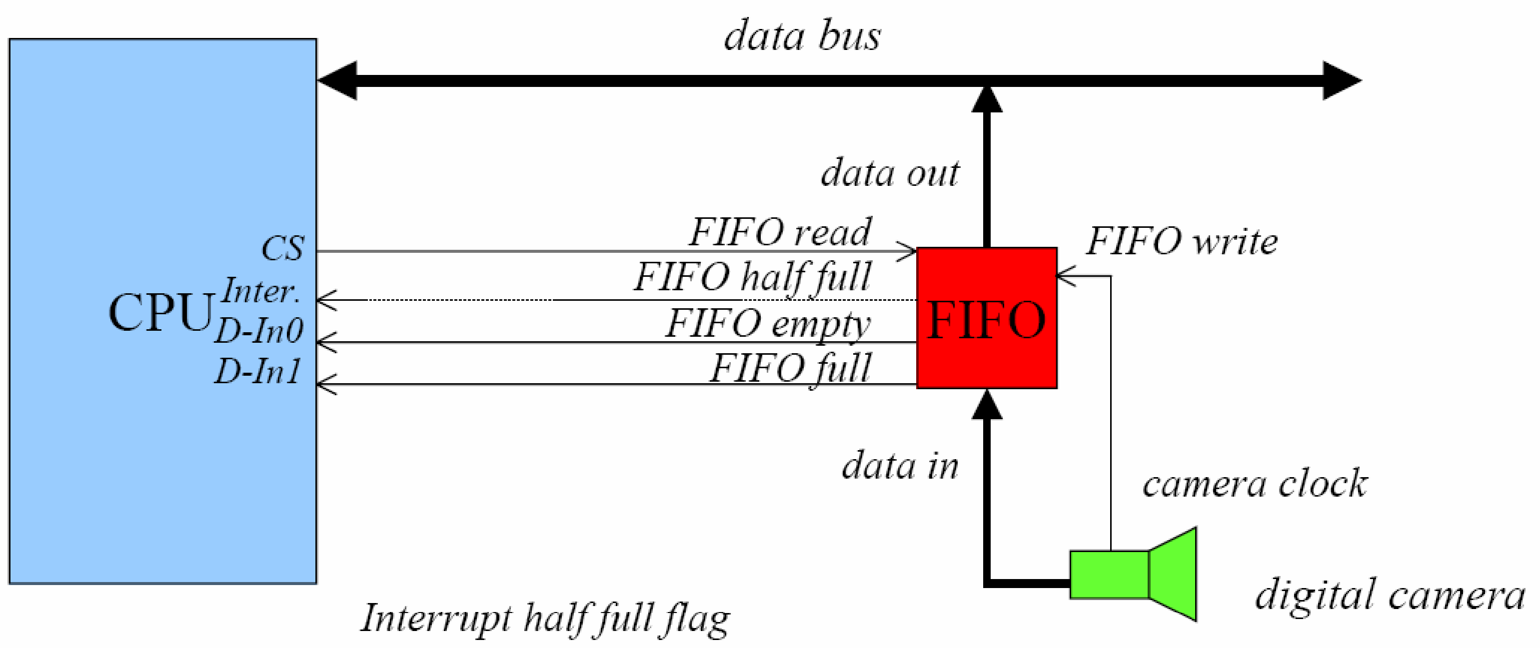
- Most sensors send full image as a **stream** after start signal
  - (CPU must be fast enough to read or use hardware buffer or DMA)

Simplified diagram of camera to CPU interface



Problem with Digital Cameras

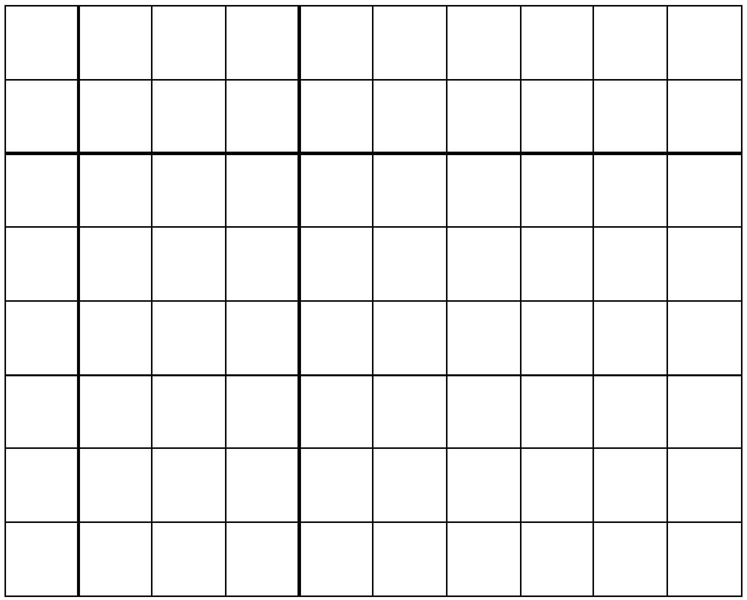
- Problem
  - Every pixel from the camera causes an interrupt
  - Interrupt service routines take long, since they need to store register contents on the stack
  - Everything is slowed down
- Solution
  - Use RAM buffer for image and read full image with single interrupt



- Idea
  - Use FIFO as image data buffer
  - FIFO is similar to dual-ported RAM, it is required since there is no synchronization between camera and CPU
  - When FIFO is half full, interrupt is generated
  - Interrupt service routine then reads FIFO until empty
    - (Assume delay is small enough to avoid FIFO overrun)

Digital Cameras

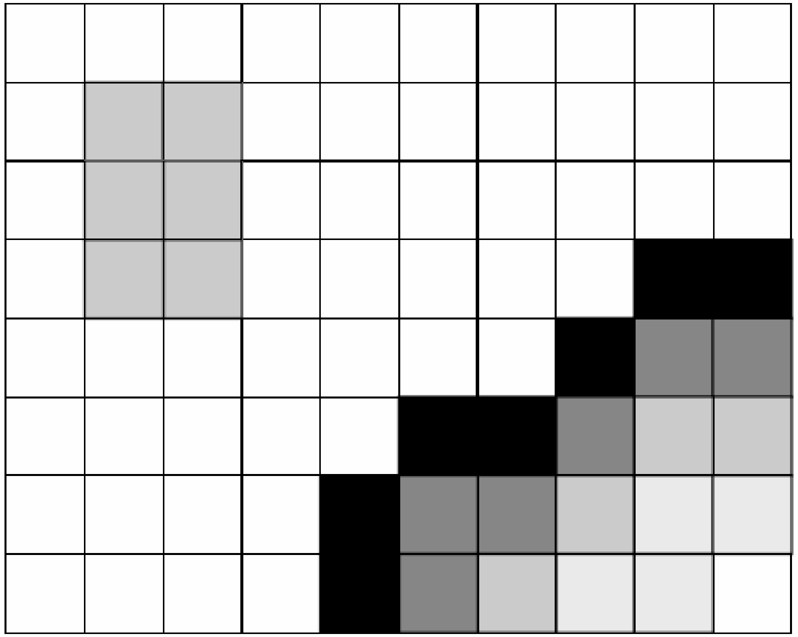
Grayscale Camera Chip: 160x120 Pixels



1 Byte per pixel

Digital Cameras

Grayscale Camera Chip: 160x120 Pixels

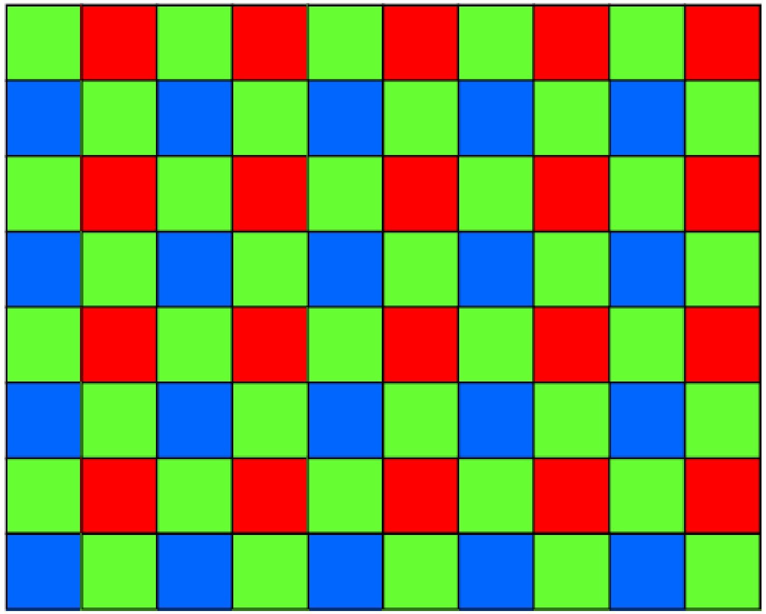


1 Byte per pixel

Digital Cameras

Bayer Pattern

Color Camera Chip: 160x120 “Pixels”



1 Byte per “square”
4 squares are 1 pixel

“Bayer Pattern”
green, red, green, red, …
blue, green, blue, green, …

Same chip as grayscale version,
just a layer of color added!

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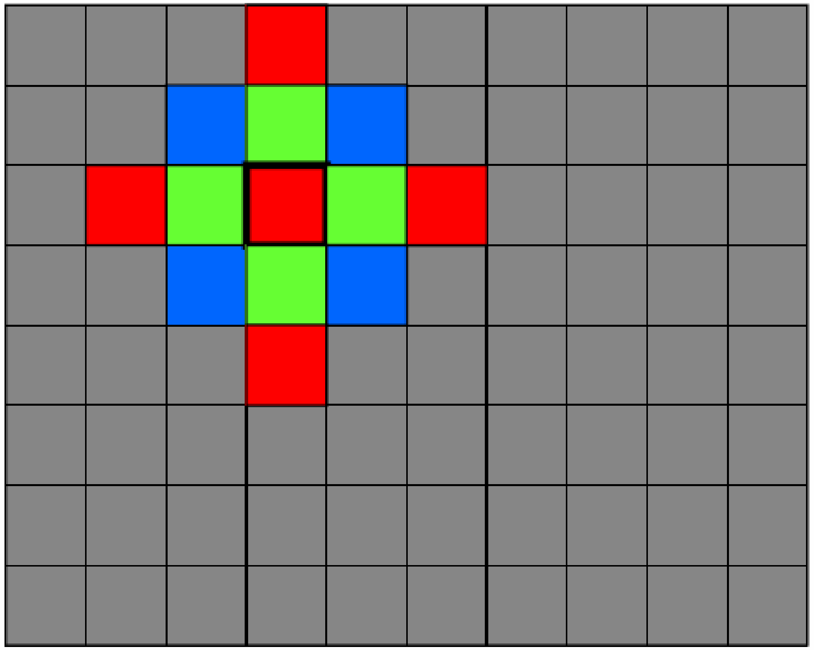
Digital Cameras

De-Mosaic

Color Camera Chip: 160x120 "Pixels"



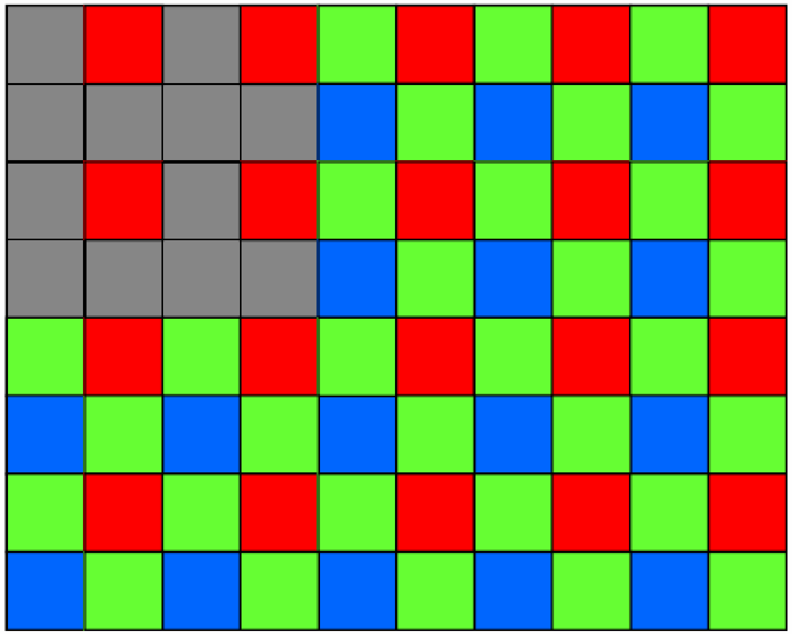
"De-Mosaic"

green, red, green, red, …
blue, green, blue, green, …

Double the resolution in x and y

Digital Cameras

Color Camera Chip: 160x120 “Pixels”



1 Byte per “square”
4 squares are 1 pixel

“Bayer Pattern”
red, green, red, green, …
green, blue, green, blue, …

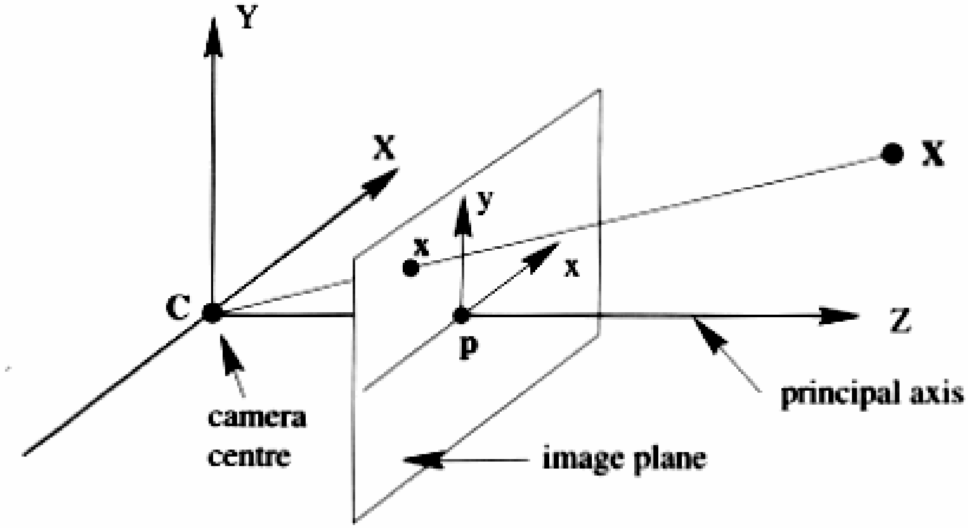
What is this ?

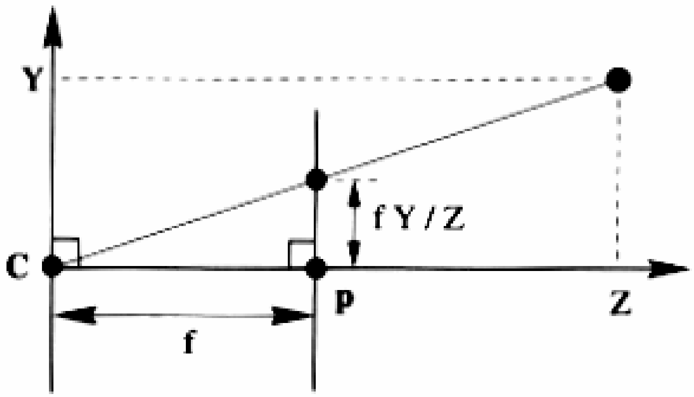
Vision Sensors

- Single Perspective Camera
- Multiple Perspective Cameras (e.g. Stereo Camera Pair)
- Laser Scanner
- Omnidirectional Camera
- Structured Light Sensor

Vision Sensors

- Single Perspective Camera



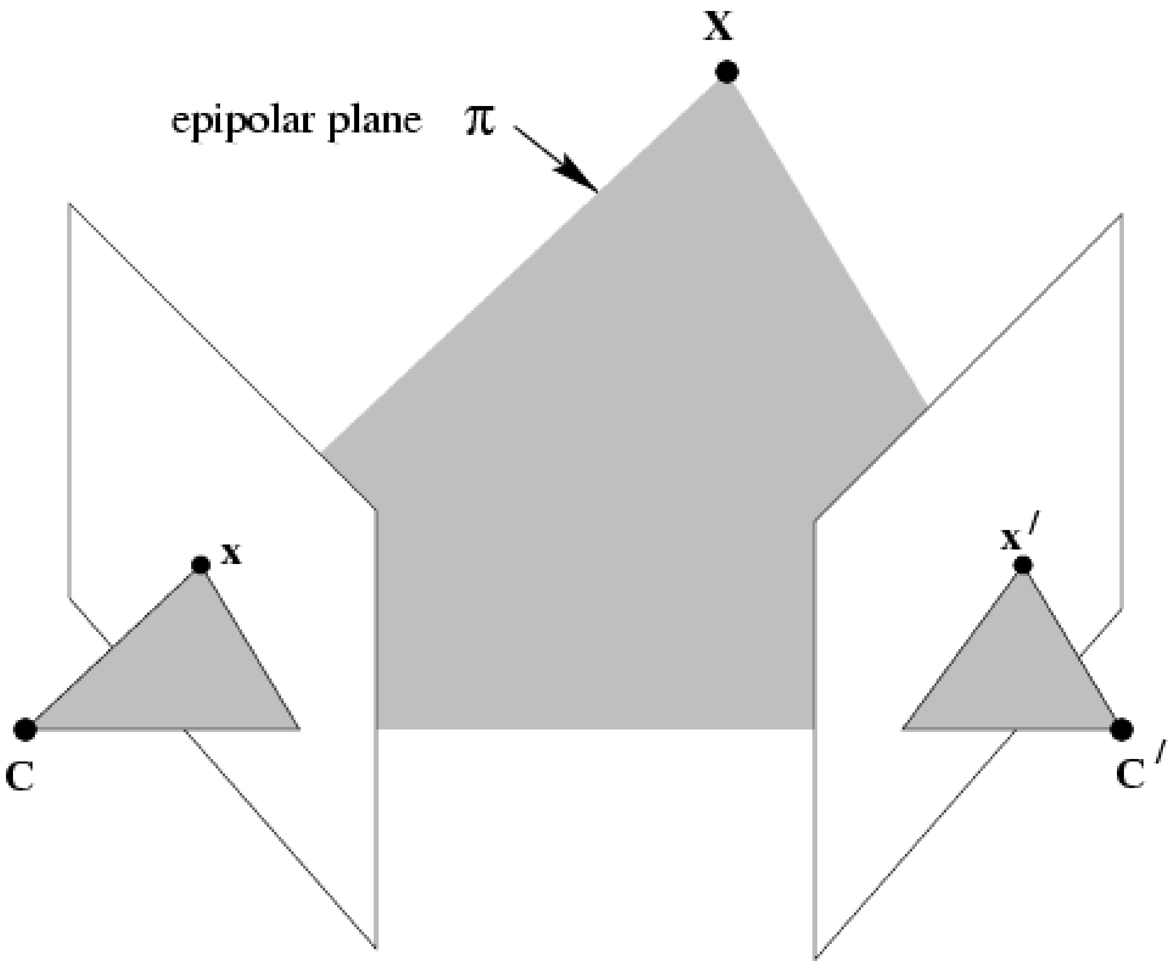


$$x = P_{3x4} X$$

Single projection

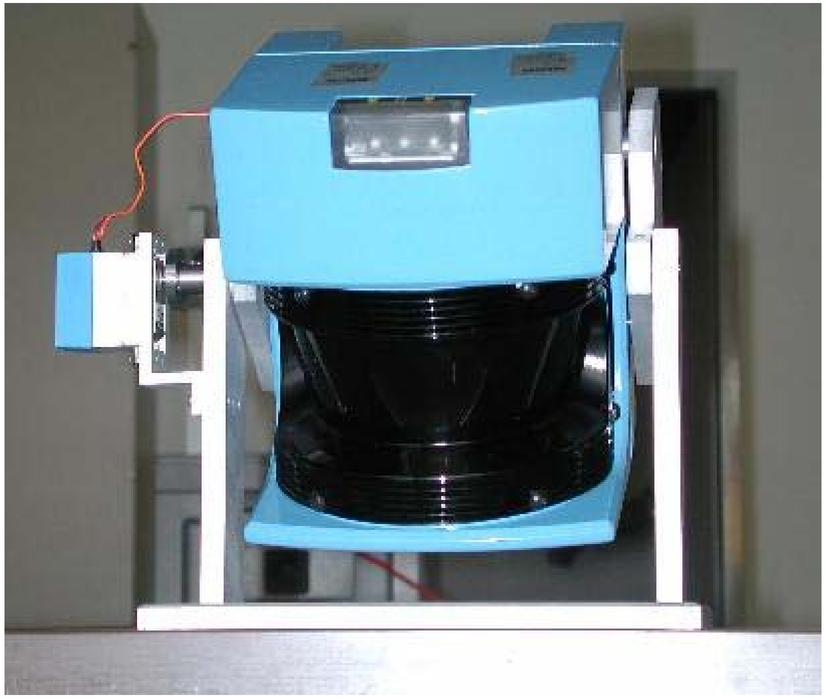
Vision Sensors

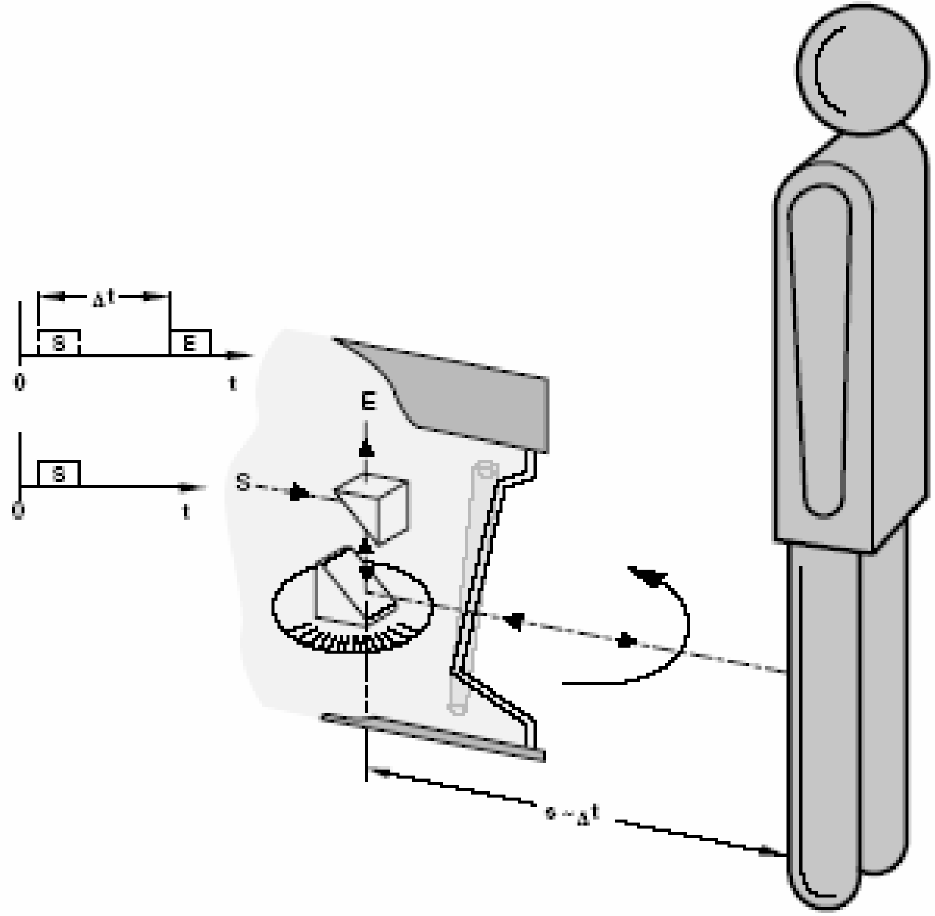
- **Multiple Perspective Cameras** (e.g. Stereo Camera Pair)



Vision Sensors

- Laser Scanner



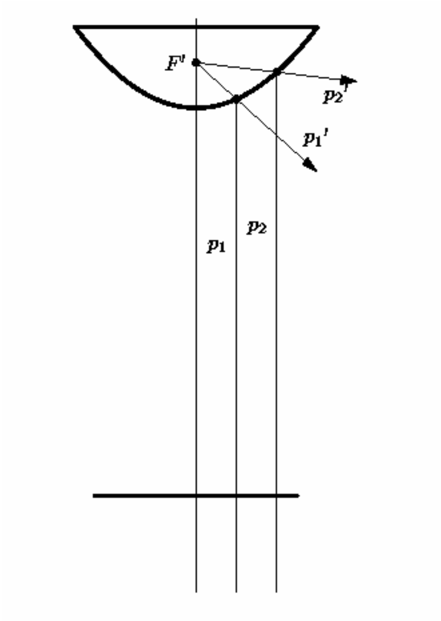


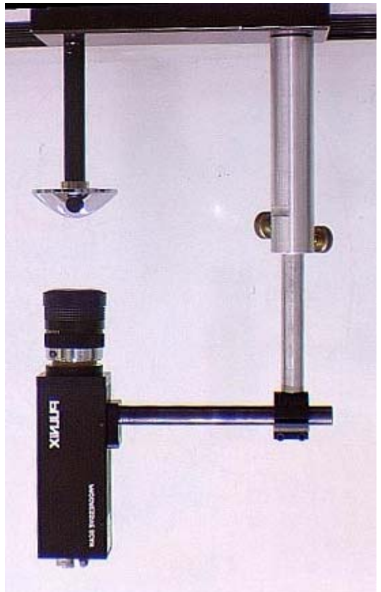
Vision Sensors

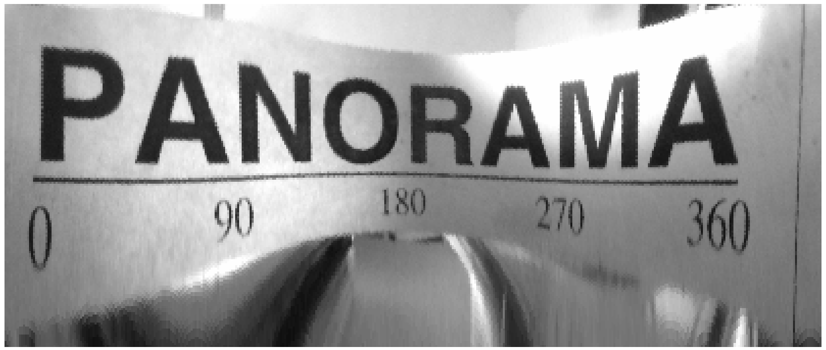
- Laser Scanner

Vision Sensors

- Omnidirectional Camera







Vision Sensors

- Omnidirectional Camera

Issues/Problems of Vision Hardware

- Measurement Frequency
- Measurement Uncertainty
- Occlusion, Camera Positioning
- Sensor dimensions

Usual assumptions for vision system (of robot)

- Man-made environment
- Floor flat and horizontal
- Wall and objects surfaces are vertical
- Static objects
- Constant Lighting
- Robot translates or rotates
- No encoders

Features and Events

Feature:

– Vertical Edges

Events:

– A new edge

– An edge disappears

– Two edges 180° apart

– Two pairs of edges 180° apart