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CENTRE FOR AUTONOMOUS SYSTEMS

41014 Sensors and Control for Mechatronic Systems

Dr. **Liang Zhao**

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0.1 Lecture-1

❖ Information of the Subject:

- Teaching Staff
- Description, Subject learning objectives
- Course Information, Lectures and Tutorial
- Quiz, Group project, Exam and marks

❖ Lecturer: Introduction of the Subject

- 2 activities

❖ Tutorial:

- “Play” with cameras in ROS
- Matlab tutorial, Read/Show/Save images using Matlab
- Write your code to convert RGB image to greyscale

0.2 Activity 2

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❖ Group discussion

- Fetch Robot Navigation and Grasping

0.2 Activity 2

- **How many problems involved in this application?**

- **What sensors and control methods are used in each problem?**

0.2 Activity 2

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❖ Problem 1: Navigation/Localization

- Robot needs to go from the starting point to the table
- Sensors: 2D laser and/or RGB-D camera

❖ Problem 2: Object recognition

- Robot needs to recognize the object, and estimate the pose
- Sensors: RGB-D camera

❖ Problem 3: Visual Servoing

- Control the robot art to pick up the object
- Sensors: RGB-D camera, force sensor

41014 Sensors and Control for Mechatronic Systems

Lecture-2: Cameras

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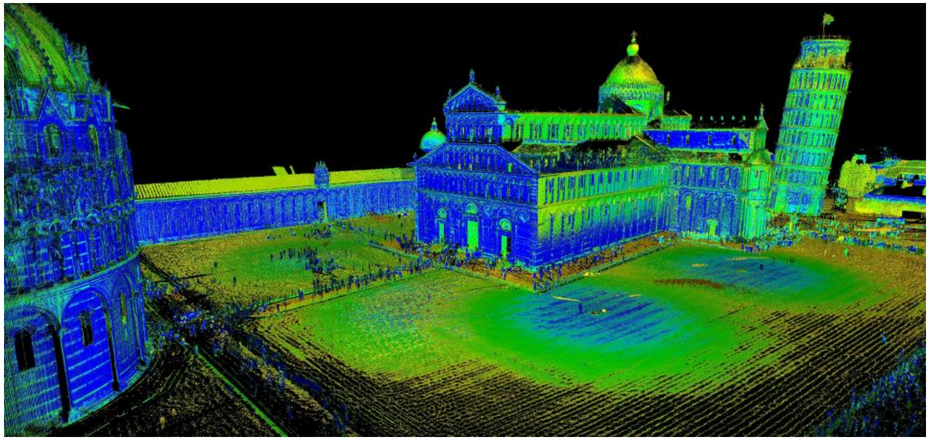
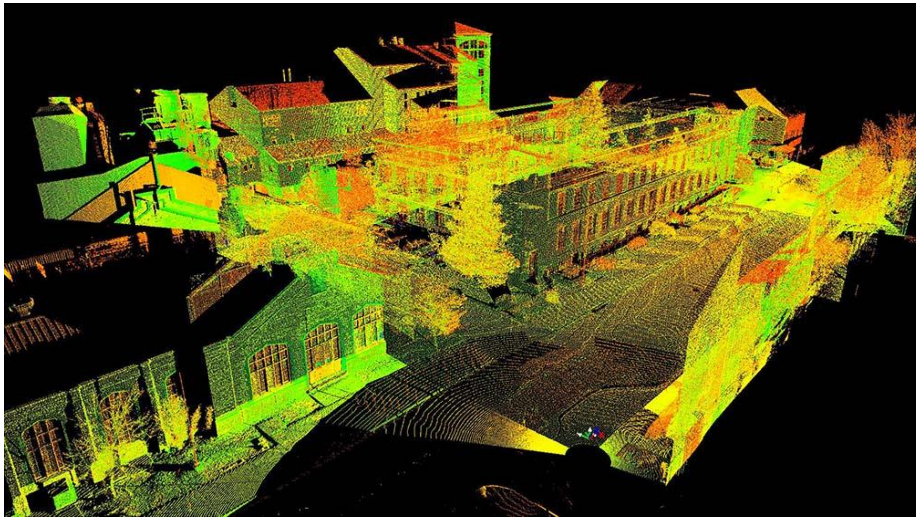
1. Lecture-2

- **Sensors:**
  - **Cameras**
  - RGB-D Cameras
  - ToF sensors

- **In details of**
  - Fundamental
  - Data and Processing





1. Lecture-2

Lecture:

- Introduction to different sensors
- Camera: Geometry
- Camera: Calibration
- Image Processing: Convolution

Active hands on:

- Camera Calibration Toolbox
- Convolution with different Kernels

2.1 Sensors

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Sensors - Definition:

- "Sensor is a transducer that receives an input signal or stimulus and responds with an electrical signal bearing a known relationship to the input"
- Handbook of modern sensors: Physics, Design and Applications, Fraden J. , Berlin, Springer Verlag, 2003

Transducer:

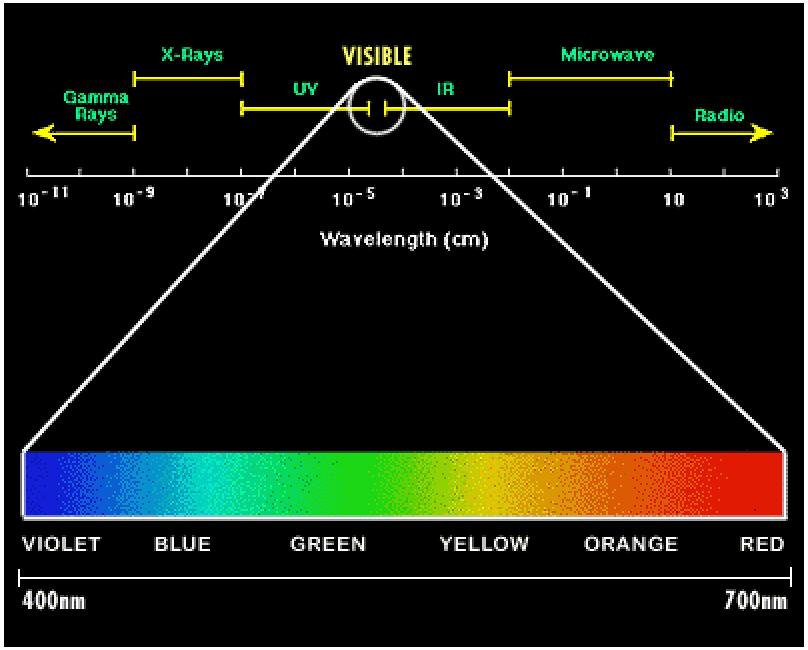
- A device that converts input energy into an output energy

Biological sensors:

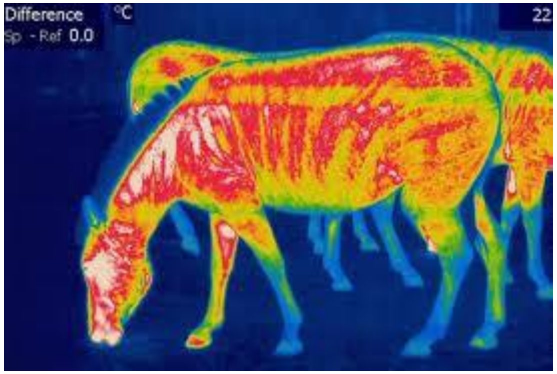
- Five senses: sight, hearing, smell, taste and touch

2.1 Sensors

- **Five senses:**
  - Sight: Our eyes are only capable of sensing a very narrow band
  - Hearing: Our ears have a limited capability to sense vibration (20Hz – 20kHz)
  - Smell, taste and touch depends on the proximity



EM spectrum



2.1 Sensors

❖ Five senses:

- Sight: Our eyes are only capable of sensing a very narrow band
- Hearing: Our ears have a limited capability to sense vibration (20Hz – 20kHz)
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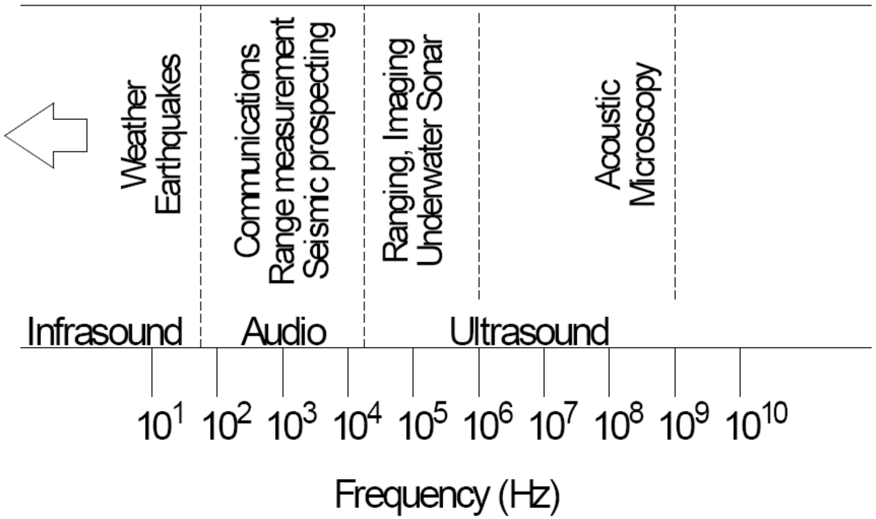
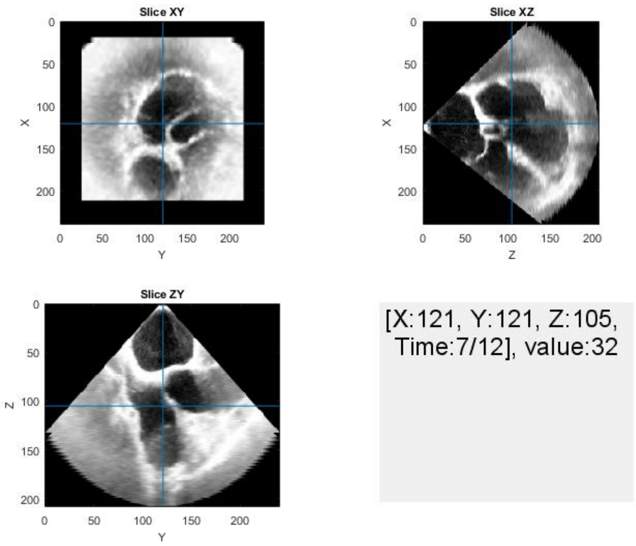


Acoustic spectrum



2.1 Sensors

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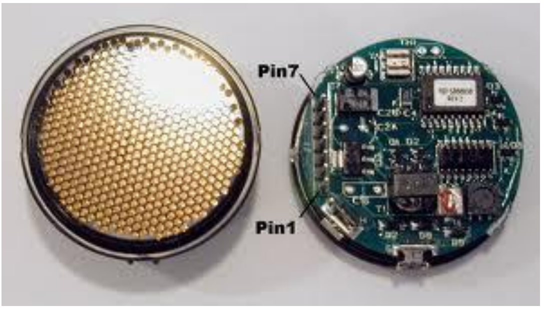
❖ Active/Passive senses:

- Active sensors require their own source of illumination: eg. Radars, laser range finders, sonars

- Passive sensors rely on natural conditions. Eg. cameras



2.2 Sensors: Sonars

❖ Sonars (Sound Navigation and Ranging)

- Titanic disaster and World Wars prompted to use acoustic technology for object detection

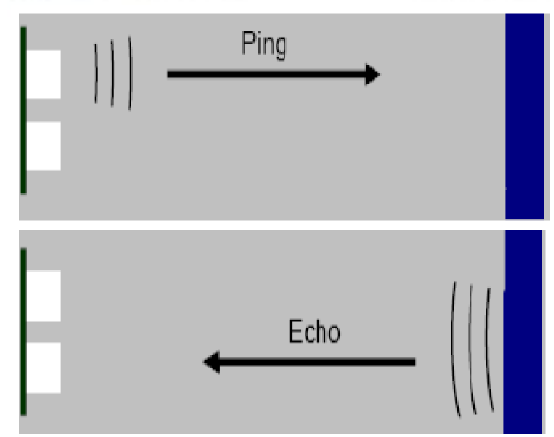
- In World War II, pencil beam sonars were used to detect submarines with a range of 2500 yards

❖ Operation

- Generating a short burst of sound (a ping)

- Listening for the echo

- Distance is calculated based on the elapsed time



2.2 Sensors: Sonars

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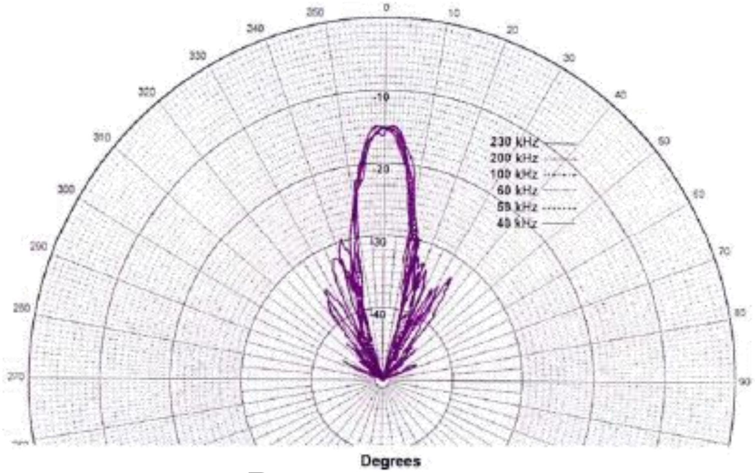
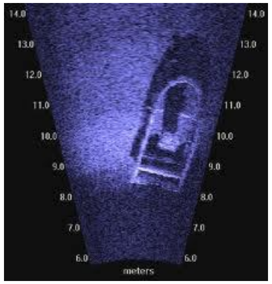
❖ Sonar applications

- Depth measurement
- Fish finding
- Mapping sea beds
- Water pipe diameter estimation
- Mine detection
- Underwater communication
- Robotics



Beam pattern



2.3 Sensors: Laser

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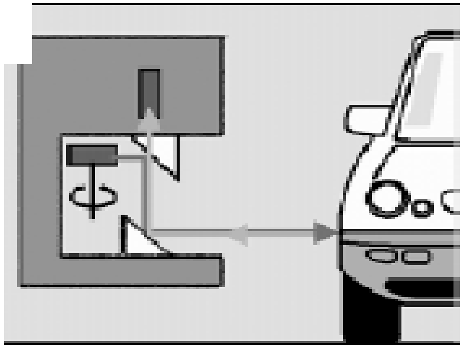
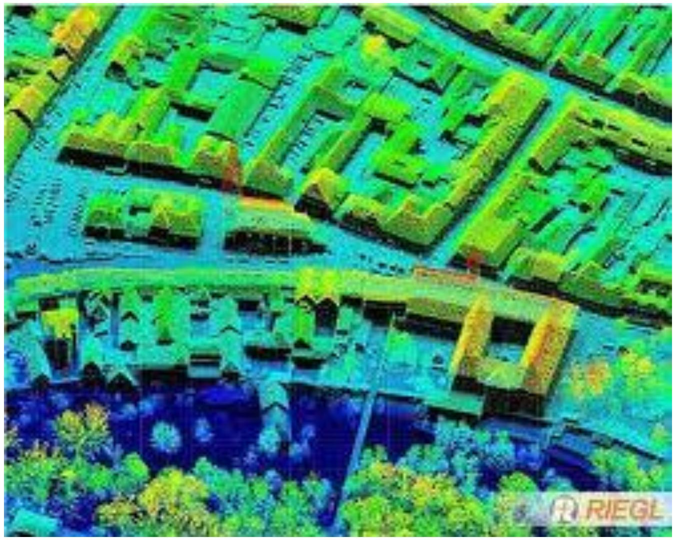
- **Laser range finders**
- **Operating principal**
  - Measuring the time of flight of laser light pulses
  - The pulsed laser beam is deflected by an internal rotating mirror
  - The measurement data is available in real time via serial interface

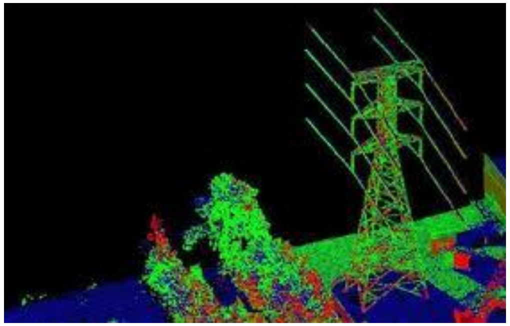


2.3 Sensors: Laser

❖ Laser range finder applications

- Surveying
- Mapping
- Area monitoring
- Localization
- Object tracking
- Robotics
- Intruder detection





2.4 Sensors: Radars

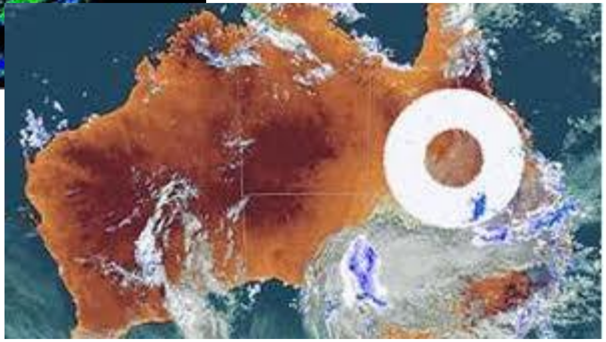
❖ Radars

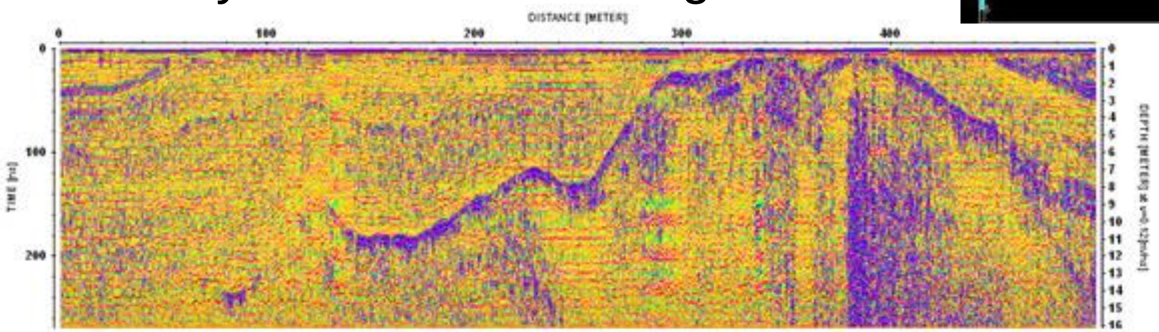
- Heinrich Hertz, generated “Hertzian waves” between 1885-1889. He showed through several experiments those waves travelled at the speed of light and could reflect, refract and polarize
- Guglielmo Marconi, 1901, transmitted 3500km
- First “echo location” was reported in 1904 (ship detection by Huelsmeyer)
- Nichola Tesla, 1917 detected position and speed of a vessel
- After the WWII the development slowed down
- 1980s mass production began

2.4 Sensors: Radars

❖ Radars applications

- Aircraft detection
- Missile guidance
- Weather forecasting
- Automotive industry
- Ground penetration radars in Geology
- GIS systems
- Sky and sea monitoring





2.5 Sensors: Cameras

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❖ Cameras

- Technology has developed significantly
- An image contains ‘squares” called pixels
- Each pixel can contain three basic colours – RGB, can have several million different colours
- Typical image sizes:
  - 3MP (Largest image size: 2048 x 1536)
  - 4MP (2272 x 1712)
  - 5MP (2592 x 1944)

Original 10x Optical 10x Digital

http://photo.net/equipment/digital/basics/

2.5 Sensors: Cameras

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- **Image formats:**
  - JPEG (Joint Photo Experts Group): Compress images with loss on information
  - TIFF (Tagged Image File Format): Lossless compression
  - RAW (Canon) Lossless compression
  - NEF (Nikon) Lossless compression

- **Interfaces:**
  - Analogue – Frame grabbers needed (old technology)
  - USB – Cheapest solution
  - Camera Link - good quality, frame gabbers needed
  - Fire Wire – most popular in robotics
  - Gigabit Ethernet (GigE) – Fast image transfer with low cost cables

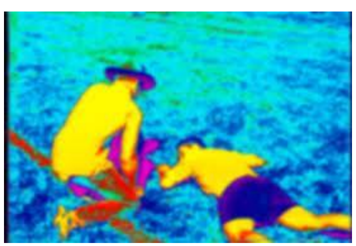
2.5 Sensors: Infra Red Camera

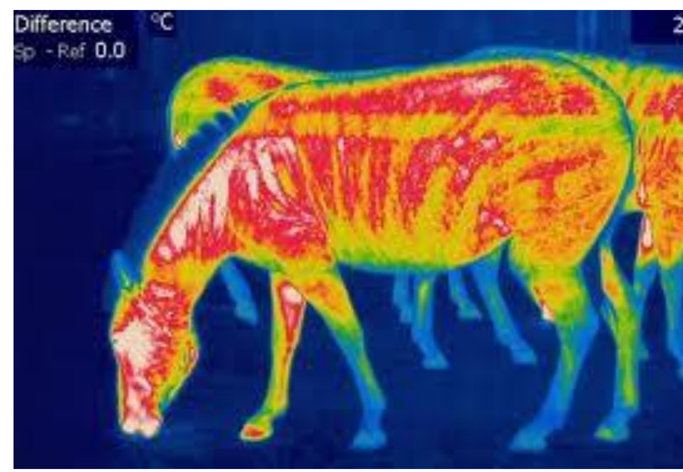
❖ Infra Red Imaging :

- IR radiation was discovered in 1800 by Sir William Herschel
- Thermopile – created using thermocouples, 1881
- Bolometer – 1878, converts changes in temperature into changes in resistance
- IR photography – 1960, cooled detectors produced line images
- 1970s – uncooled detectors

❖ Applications:

- Body temperature measurements
- Airport thermal scanning
- Fire fighting (hot spot detection)
- Aircraft and missile detection
- Surveillance
- Medical applications





3. Cameras: Geometry

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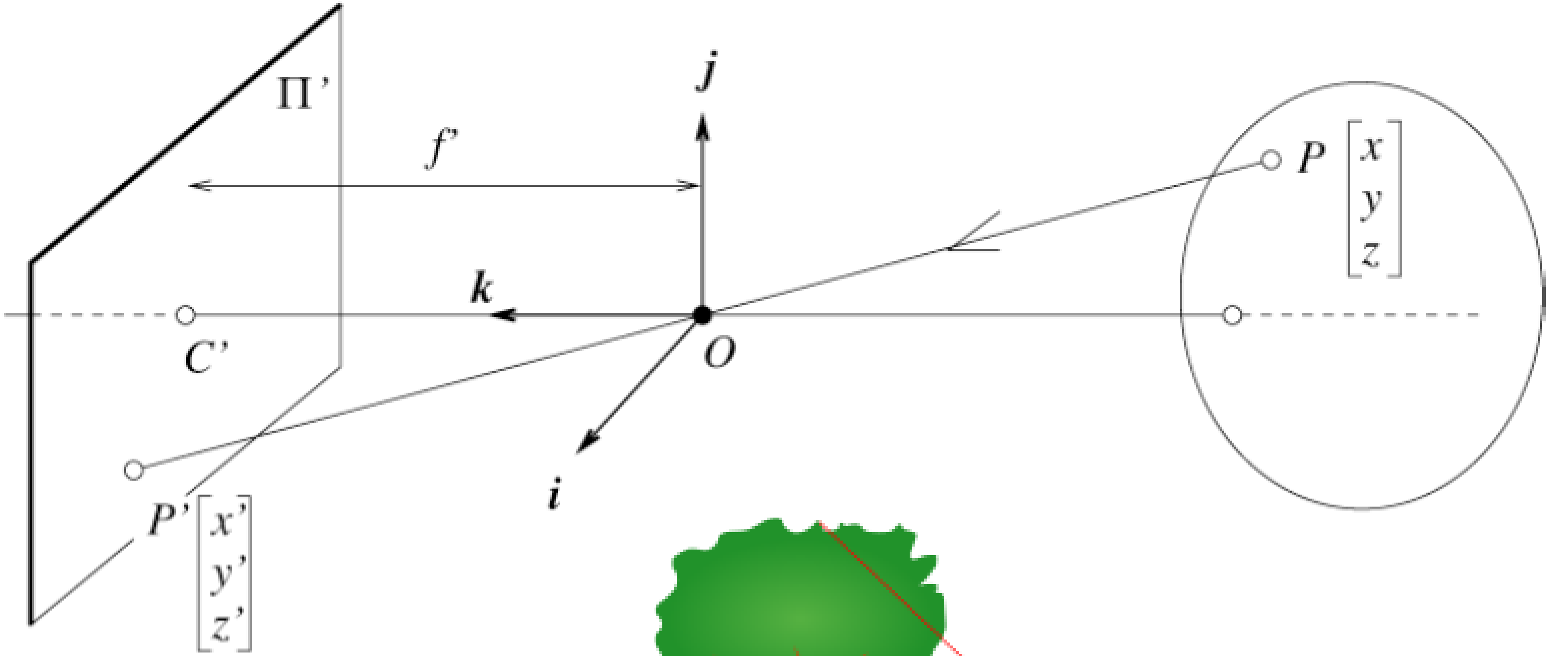
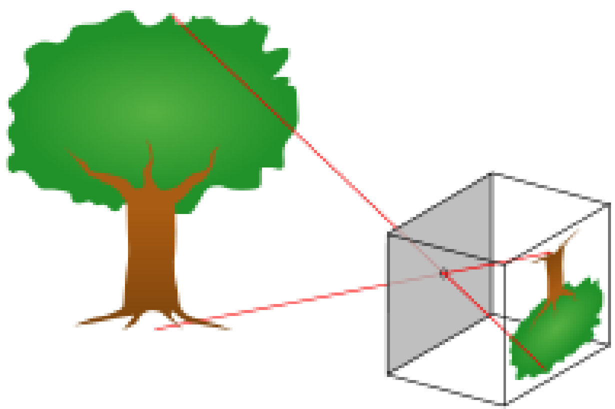
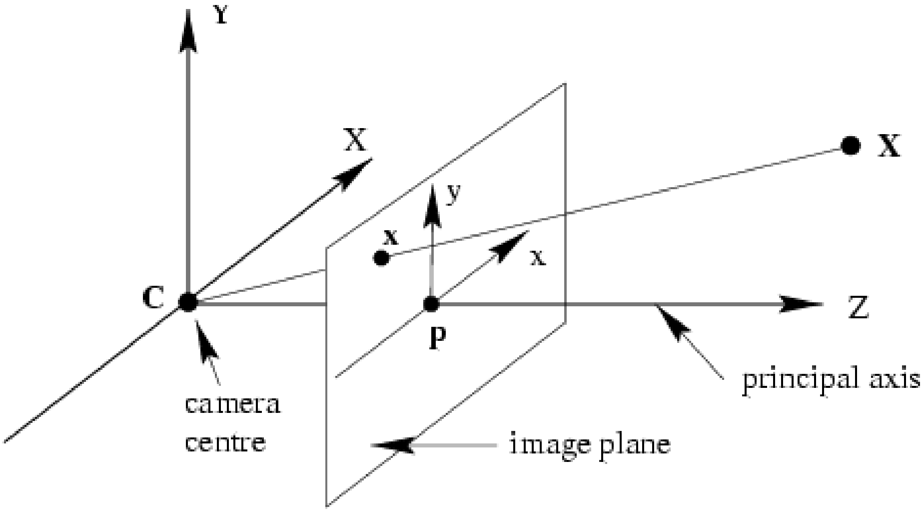
- **Single View Geometry**

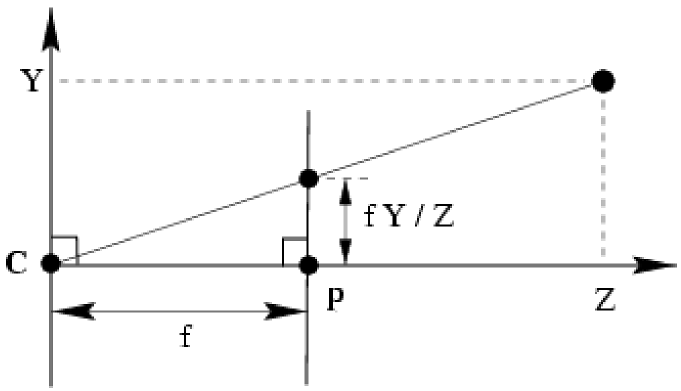
- **Pinhole model**





❖ Central projection





$$\mathrm{X} = [x, y, z]'$$

$$[x, y, z]' \rightarrow [f\frac{x}{z}, f\frac{y}{z}]' = \mathrm{x}$$

principle point, image plane, principal axis, camera centre

3. Cameras: Geometry

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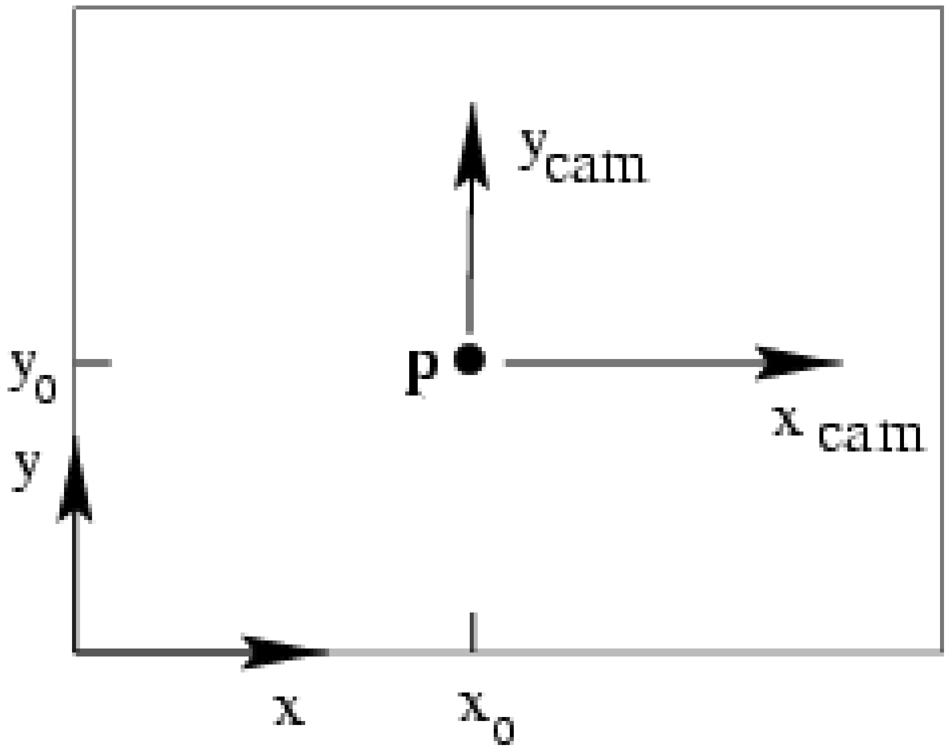
❖ Central projection with principle point offset



$[p_x, p_y]'$ **is the coordinates of the principle point in image plane**

3. Cameras: Geometry

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- **Central projection with principle point offset**

$$[x, y, z]' \rightarrow [f\frac{x}{z}, f\frac{y}{z}]' = \mathrm{x}$$

$$[x, y, z]' \rightarrow [f\frac{x}{z} + p_x, f\frac{y}{z} + p_y]' = \mathrm{x}$$

3. Cameras: Geometry

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❖ Central projection with principle point offset

$$\begin{bmatrix} fx + zp_x \\ fy + zp_y \\ z \end{bmatrix} = \begin{bmatrix} f & 0 & p_x & 0 \\ 0 & f & p_y & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$[p_x, p_y]'$ **is the coordinates of the principle points in image plane**

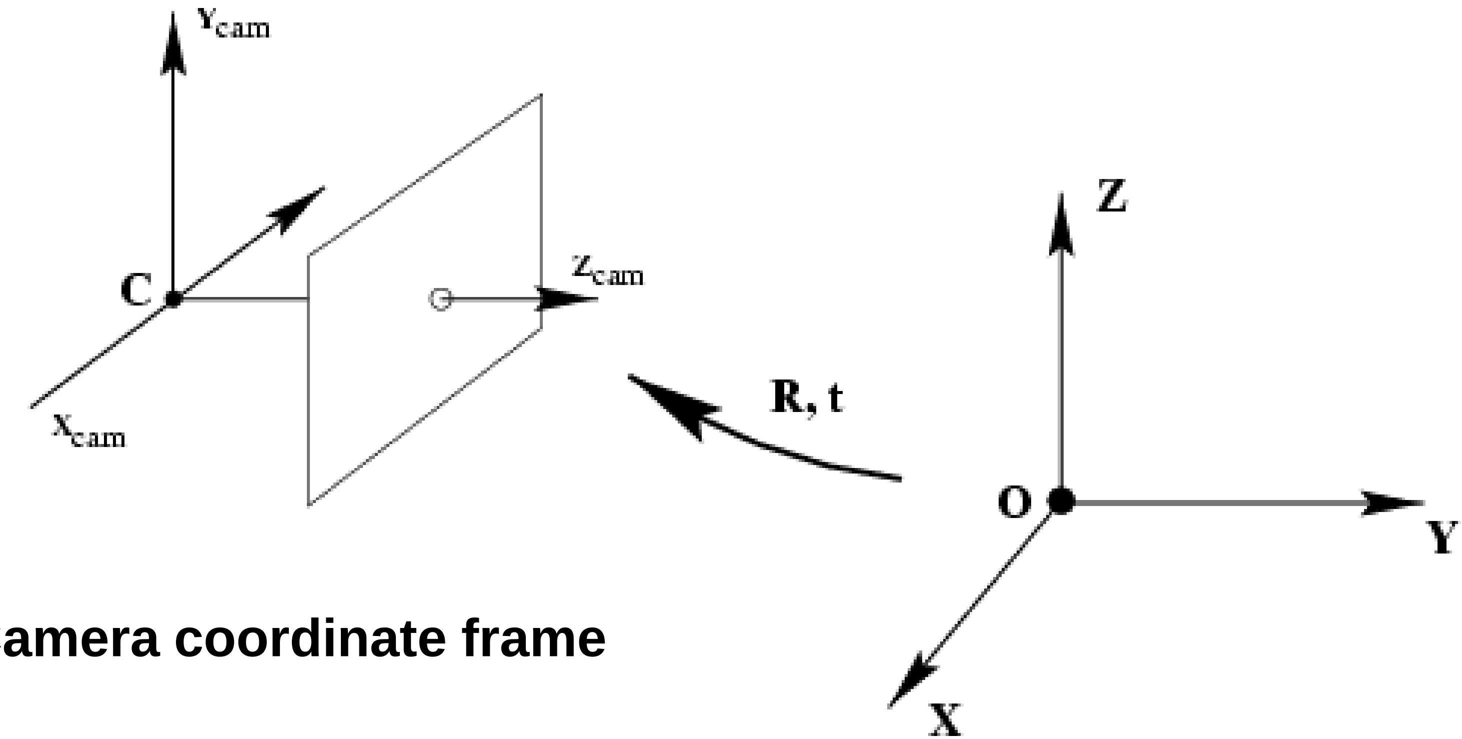
$$\mathrm{x} = \mathrm{K}[\mathrm{I} \mid \mathbf{0}]\mathrm{X}_{\mathrm{cam}}$$

homogeneous

$$K = \begin{bmatrix} f & 0 & p_x \\ 0 & f & p_y \\ 0 & 0 & 1 \end{bmatrix}$$

K is camera calibration matrix; X_cam is in camera coordinate frame

Camera rotation and translation



Camera coordinate frame

World coordinate frame

Camera is on a moving vehicle. Object is in a global reference frame.

3. Cameras: Geometry

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General camera projection

$$
\begin{aligned}
\mathrm{x} &= \mathrm{K}[\mathrm{I} \mid 0]\mathrm{X}_{\mathrm{cam}} \\
&= \mathrm{K}[\mathrm{I} \mid 0]\begin{bmatrix} R & -R\tilde{C} \\ 0 & 1 \end{bmatrix}\mathrm{X}
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{x} &= \mathrm{KR}[\mathrm{I} \mid -\tilde{\mathrm{C}}]\mathrm{X} \\
&= \mathrm{PX}
\end{aligned}
$$

$$\mathrm{P} = \mathrm{KR}[\mathrm{I} \mid -\tilde{\mathrm{C}}]$$

P is camera projection matrix

K: camera intrinsic parameters; R,C: camera extrinsic parameters

3. Cameras: Geometry

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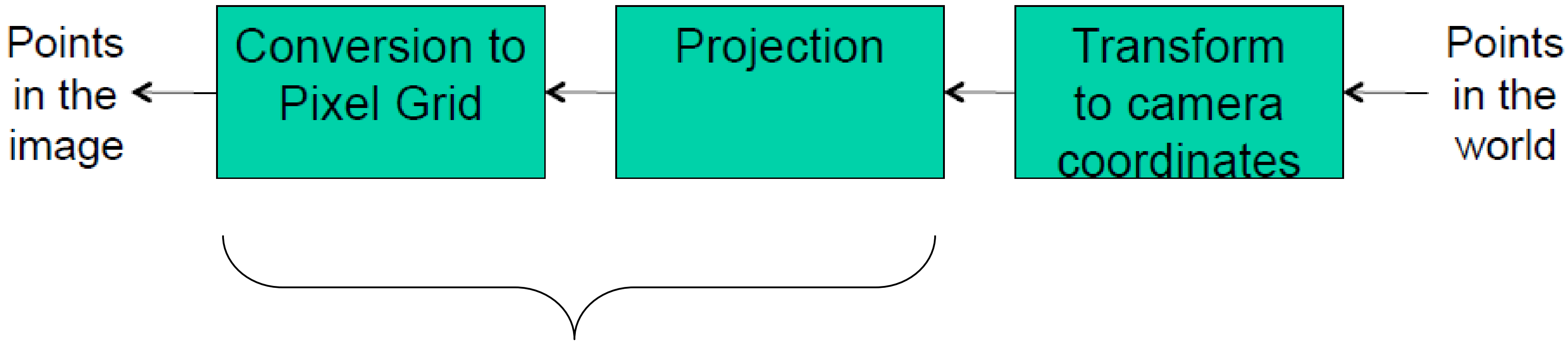
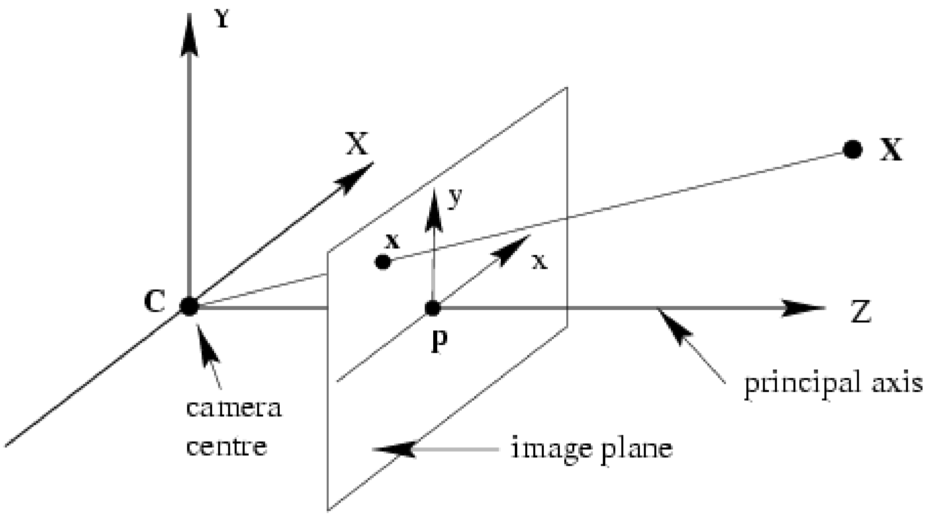
❖ The Projection "Chain"

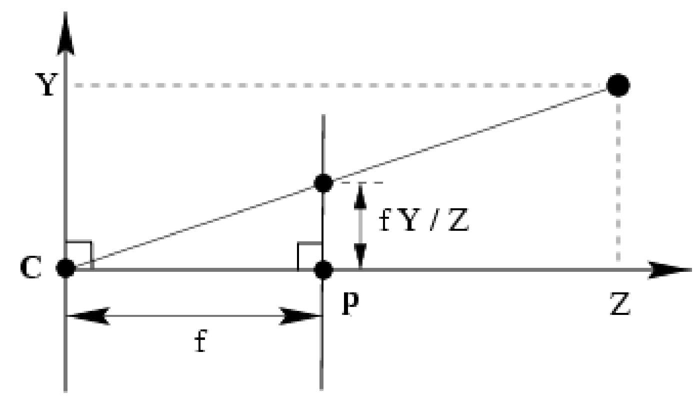


$x = (u, v)$ $\quad$ K $\quad$ X_{cam} $\quad$ X

❖ Activity 1

- Image resulotion: 1024*768
- Principle point: (520,389)
- Focal length: 935
- 3D Point in camera frame (15,10,80)
- **Image point (u,v)?**





3. Cameras: Geometry

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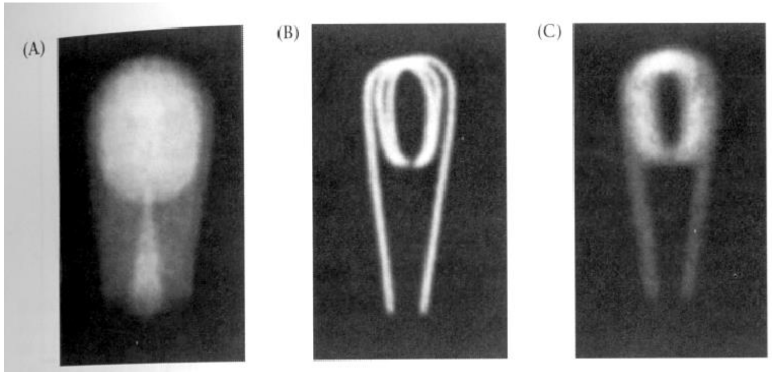
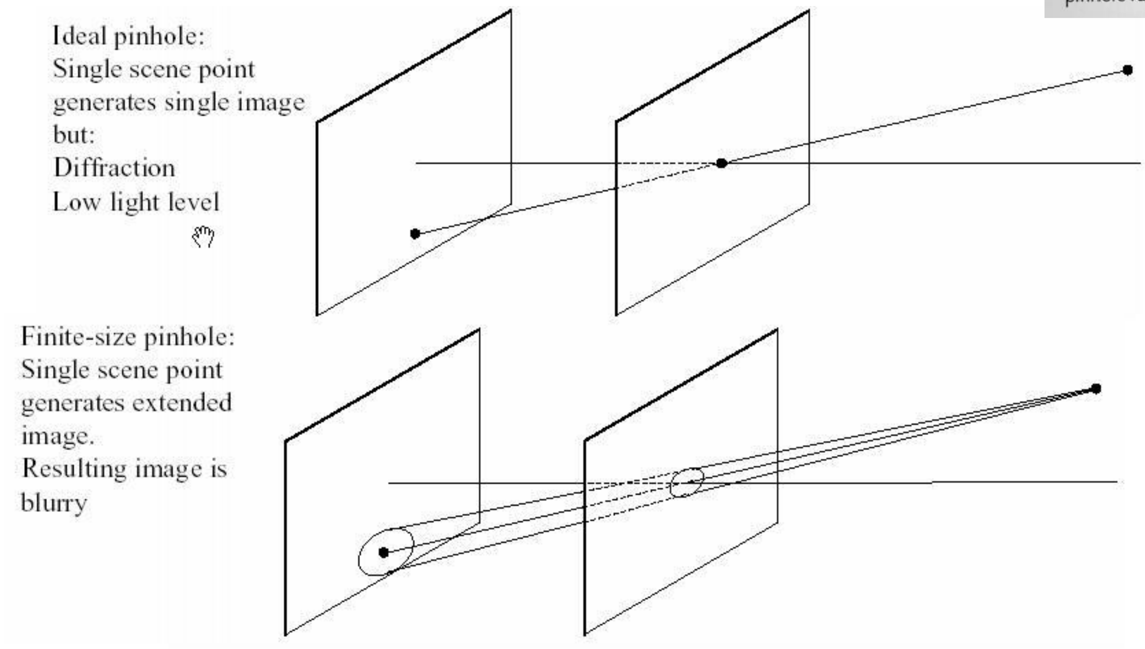
❖ **Limitations of the pin hole model**



2.18 DIFFRACTION LIMITS THE QUALITY OF PINHOLE OPTICS. These three images of a bulb filament were made using pinholes with decreasing size. (A) When the pinhole is relatively large, the image rays are not properly converged, and the image is blurred. (B) Reducing the size of the pinhole improves the focus. (C) Reducing the size of the pinhole further worsens the focus, due to diffraction. From Ruechardt, 1958.



3. Cameras: Geometry

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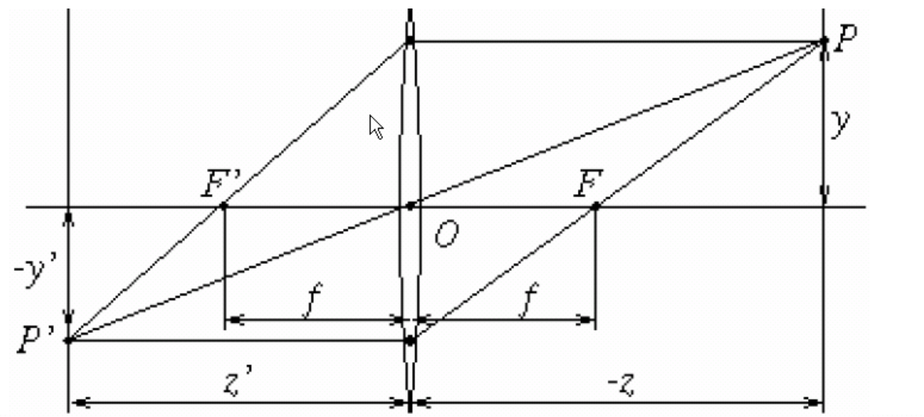
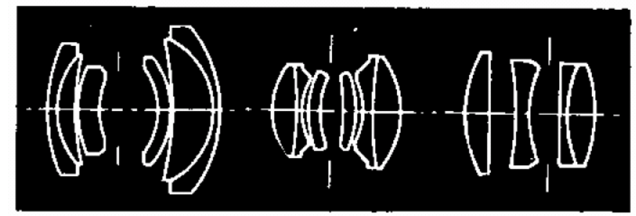
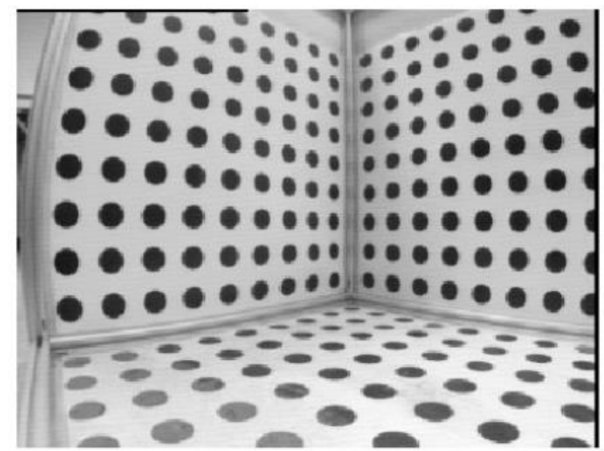
❖ Distortion





Camera lens



Geometric distortion

4. Cameras: Calibration

What to calibrate:

- the camera intrinsic (4 or more) and extrinsic parameters (6) using only observed camera data

General strategy:

- view calibration object
- identify image points
- obtain camera matrix by minimizing error
- obtain intrinsic parameters from camera matrix

Multi-Plane Calibration

- Hybrid method:Photogrammetric and Self-Calibration
- Uses a planar pattern imaged multiple times (inexpensive).
- Used widely in practice and there are many implementations.
- Based on a group of projective transformations called homographies.

Paper: Z. Zhang

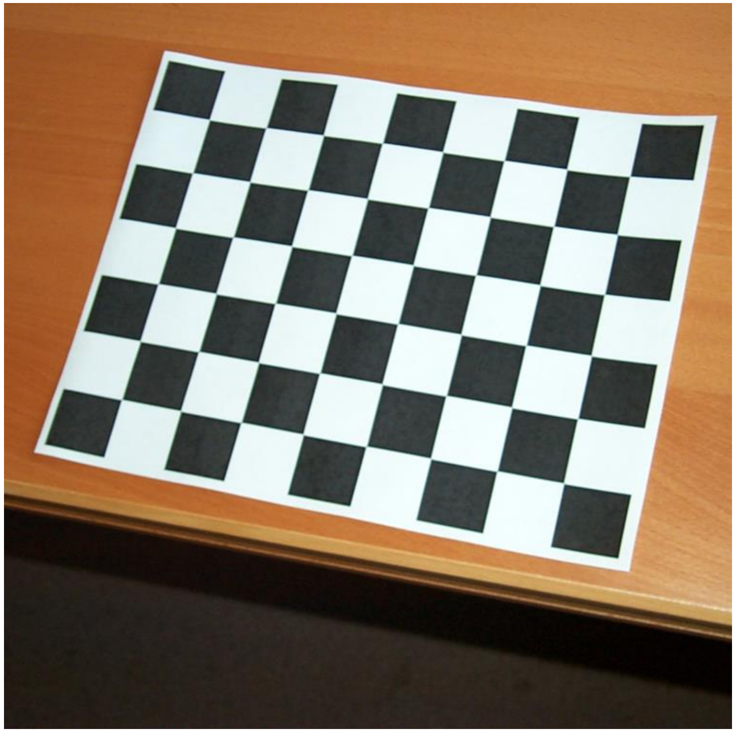
- A flexible new technique for camera calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence, 22(11):1330-1334, 2000.

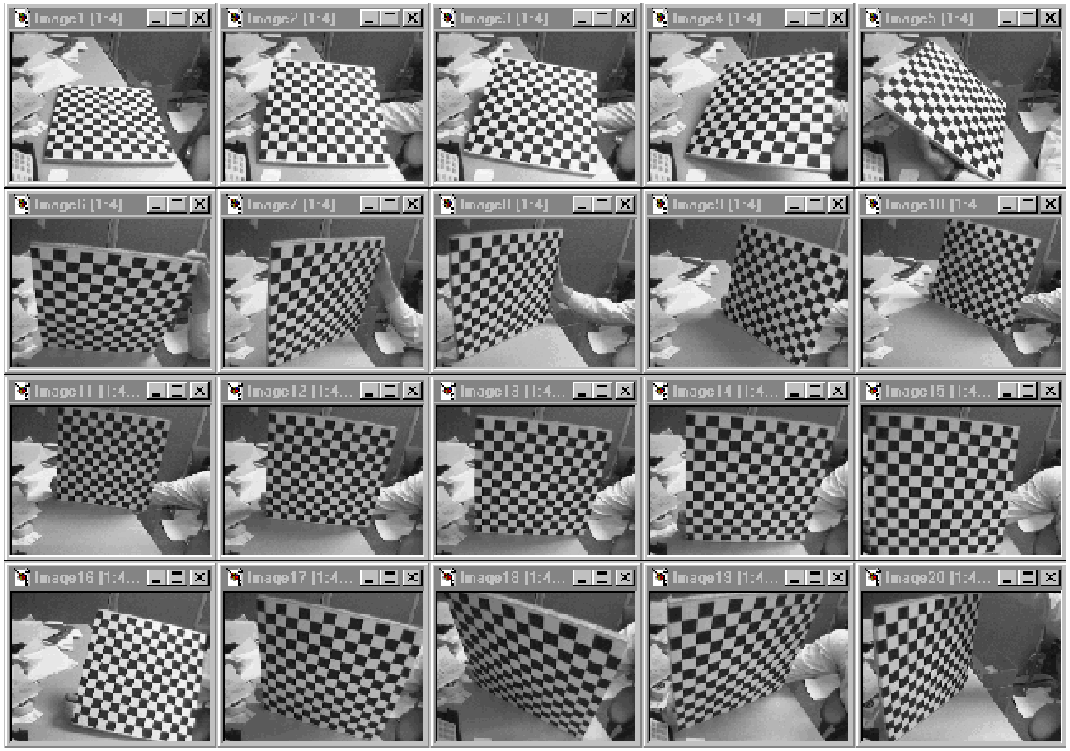
Matlab implementation:

- http://www.vision.caltech.edu/bouguetj/calib_doc/index.html

4. Cameras: Calibration

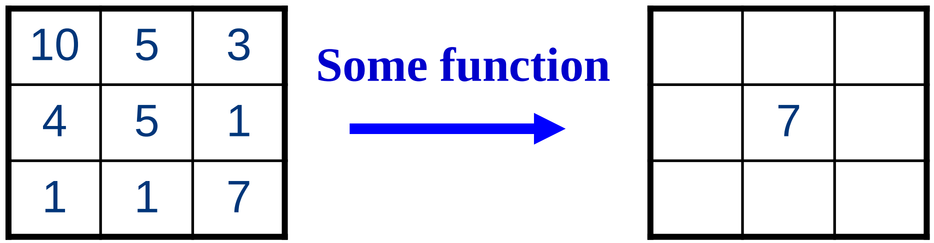
- **Matlab implementation:**
  - http://www.vision.caltech.edu/bouguetj/calib_doc/index.html





5. Cameras: Convolution

❖ **Modify the pixels in an image based on some function of a local neighborhood of the pixels**



❖ **Linear case is simplest and most useful**

- Replace each pixel with a linear combination of its neighbors.
- The prescription for the linear combination is called the convolution kernel.

5. Cameras: Convolution

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- **Modify the pixels in an image based on some function of a local neighborhood of the pixels**

10	5	3
4	5	1
1	1	7

Some function →

	7	

10	5	3
4	5	1
1	1	7

$\otimes$

0	0	0
0	0.5	0
0	1.0	0.5

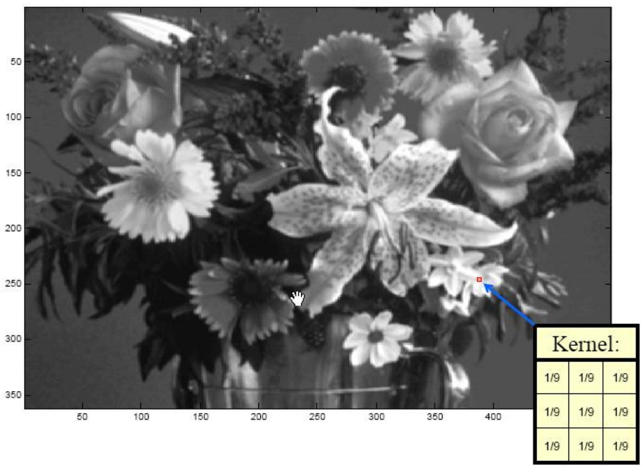
kernel

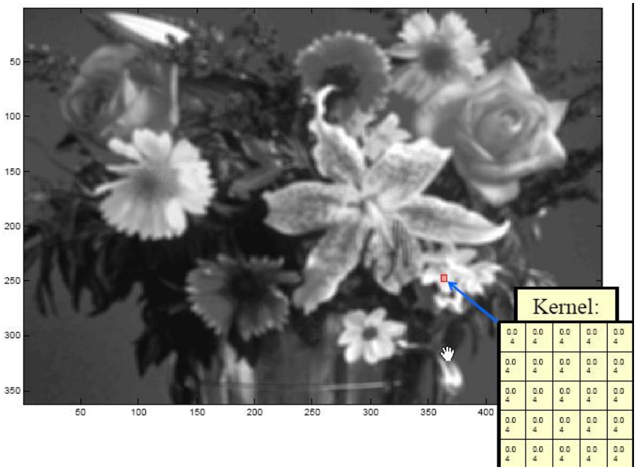
$=$

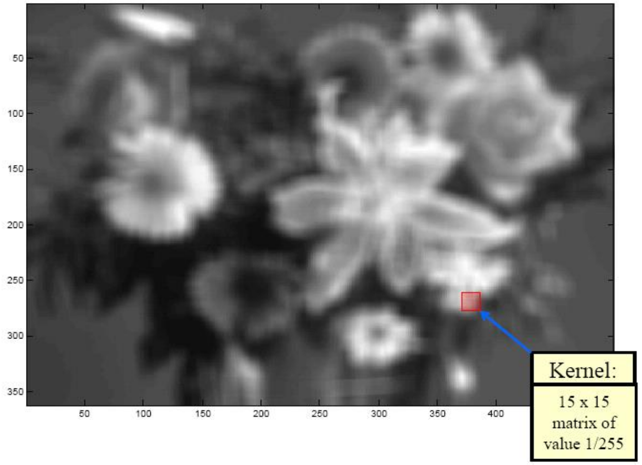
	7	

5. Cameras: Convolution

❖ Convolution: Blurring







5. Cameras: Convolution

Operation	Kernel	Image result
Identity	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	
Edge detection	$\begin{bmatrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ -1 & 0 & 1 \end{bmatrix}$	
	$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$	
	$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$	

https://en.wikipedia.org/wiki/Kernel_(image_processing)

5. Cameras: Convolution

Sharpen	$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$	
Box blur (normalized)	$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$	
Gaussian blur 3 × 3 (approximation)	$\frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$	
Gaussian blur 5 × 5 (approximation)	$\frac{1}{256}\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix}$	

https://en.wikipedia.org/wiki/Kernel_(image_processing)

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Activity 2

$$\begin{bmatrix} 0 & 25 & 50 & 100 \\ 25 & 50 & 100 & 50 \\ 50 & 100 & 50 & 25 \\ 100 & 50 & 25 & 0 \end{bmatrix} \otimes \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} = ?$$

5. Cameras: Convolution

- **Activity 2**

$$\begin{bmatrix} 0 & 25 & 50 & 100 \\ 25 & 50 & 100 & 50 \\ 50 & 100 & 50 & 25 \\ 100 & 50 & 25 & 0 \end{bmatrix} \otimes \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 50 & -200 \\ -200 & 50 \end{bmatrix}$$

UTS:CAS

CENTRE FOR AUTONOMOUS SYSTEMS

41014 Sensors and Control for Mechatronic Systems

Next Lectures

Dr. **Liang Zhao**

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University of Technology, Sydney

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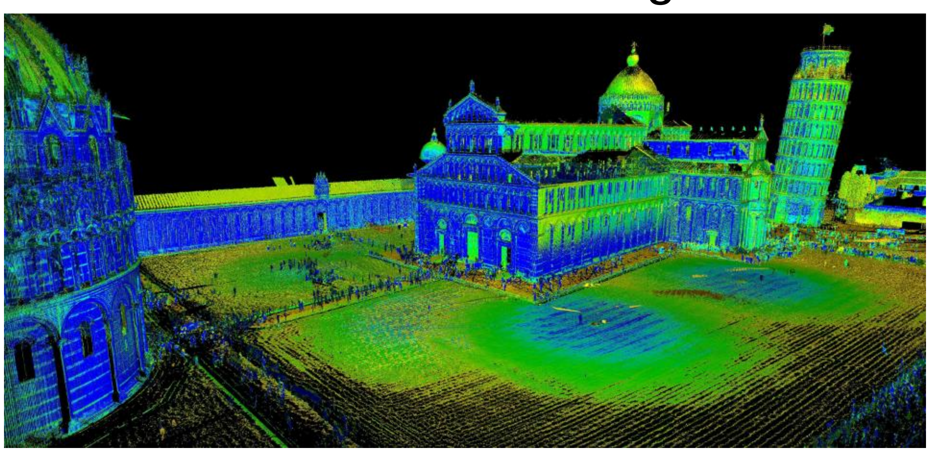
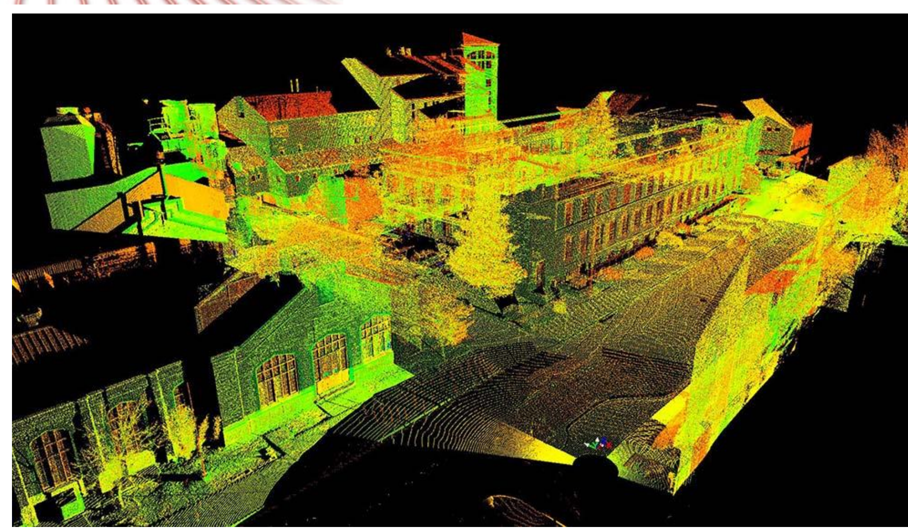
6. Next Lectures

- **Sensors:**
  - Cameras
  - **RGB-D Cameras**
  - ToF sensors
- **In details of**
  - Fundamental
  - Data and Processing





THANK YOU

Questions?