INTRO ROBOTICS AND VISION

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Learning Objectives

- Broaden horizons on the robots’ applications
- Knowledge of robots used in major industries
- Connection with visual sensors and properties
- Example on person detection

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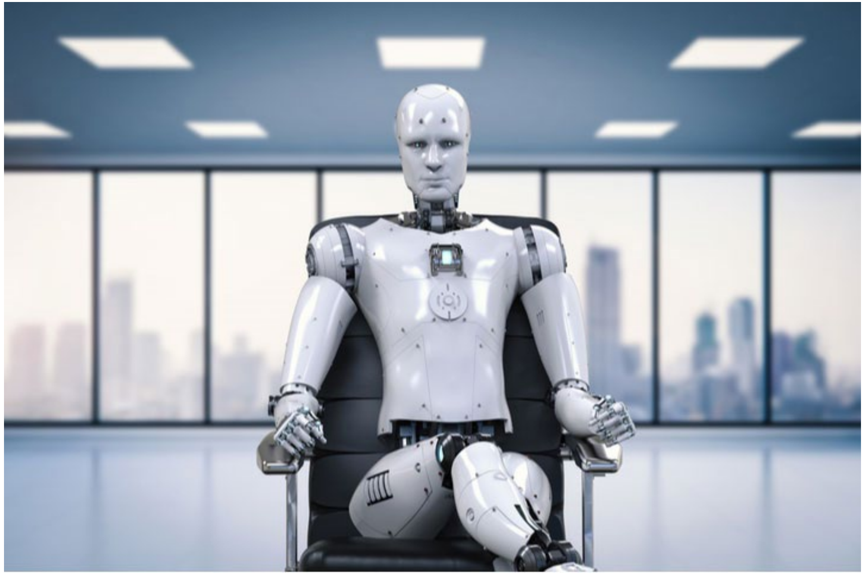
What is a Robot?

A goal-oriented machine that can sense, plan and act automatically



Why Robots?

- High precession
- Increased load capabilities
- Multi-tasking
- Repeat tasks with high accuracy
- Not affected by the monotony of tasks
- Robots can Collaborate with each other and to some extent they can collaborate with workers
- For humans to avoid hazardous areas
- Many robots can be reprogrammed to execute different tasks

→

- Increased productivity
- Increased efficiency
- Cutting production costs
- Safer work environment

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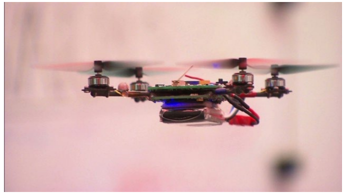
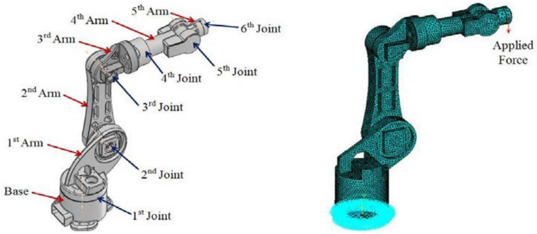
Robot types

- Robotic arms
- Mobile
- MAVs
- AUVs
- Legged
- Humanoid





(a) (b)

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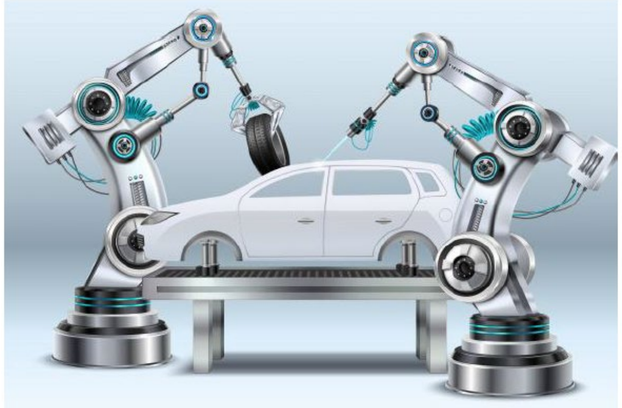
Where the Robots can be Used?

Industries that booming due to the increase in robot use:

- Manufacturing
- Agriculture
- Food Preparation
- Search and Rescue
- Pharmaceutical Industry
- Maintenance, Inspection and Repair
- Mining and Construction

Robot Sectors - Manufacturing



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Robot Sectors - Agriculture

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Robot Sectors – Food Industry

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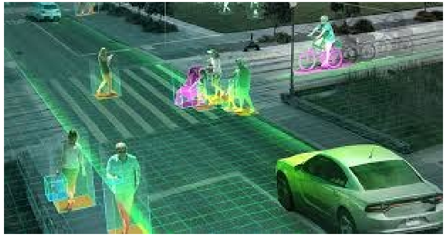
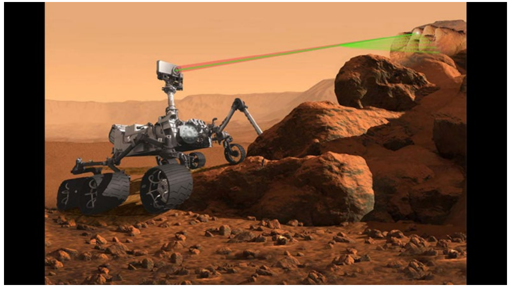
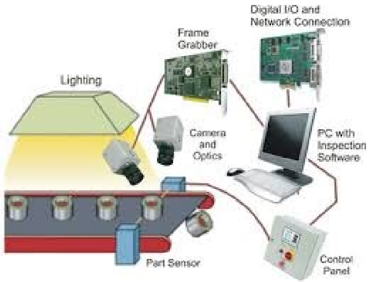
Robot Sectors – Search and Rescue

Delivery of time critical services

What is machine vision?







Automatic extraction of “meaningful” information from images and videos

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Vision in Robotics

Focuses on computer vision methodologies and technical solutions applied to advanced robotic systems using conventional and intelligent paradigms

Vision in Robotics - Steps

- Object detection and tracking
- Feature extraction
- Object model acquisition

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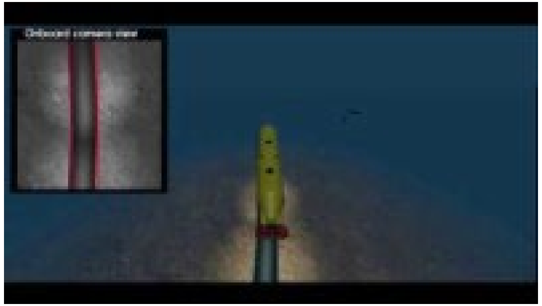
Focus on Vision



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Vision in Robotics - Challenges

- Sensor Frame Rate
- Image/Depth processing
- Occlusion
- Viewpoint Handling
- Out-of-View events
- Clutter
- Camera Positioning
- Field of View

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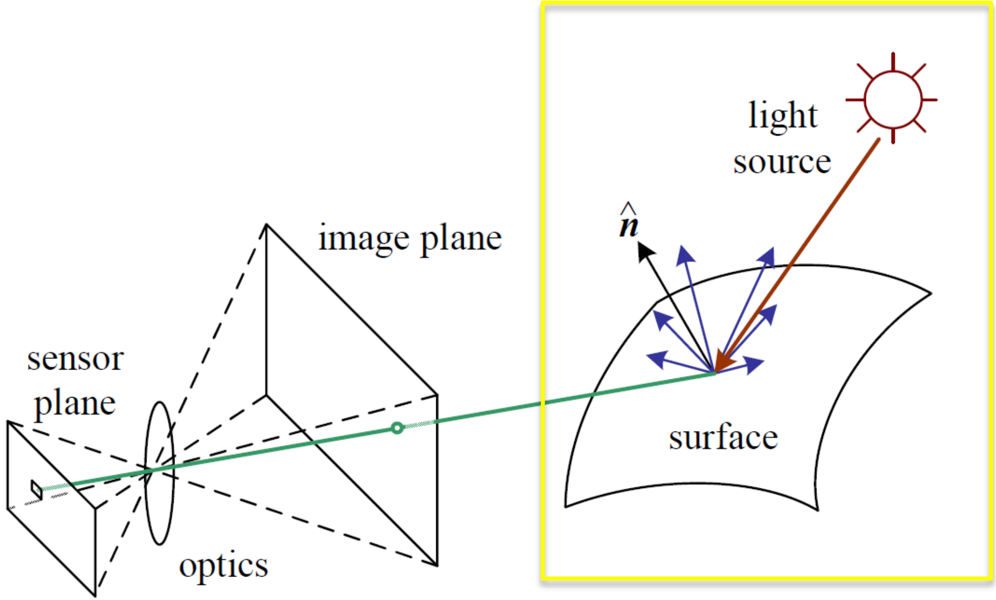
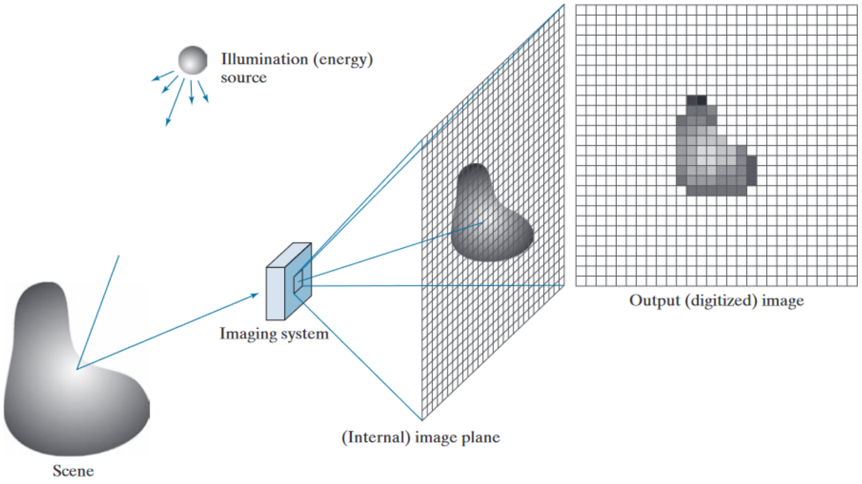
Image formation



Photometric Image formation - The digital camera



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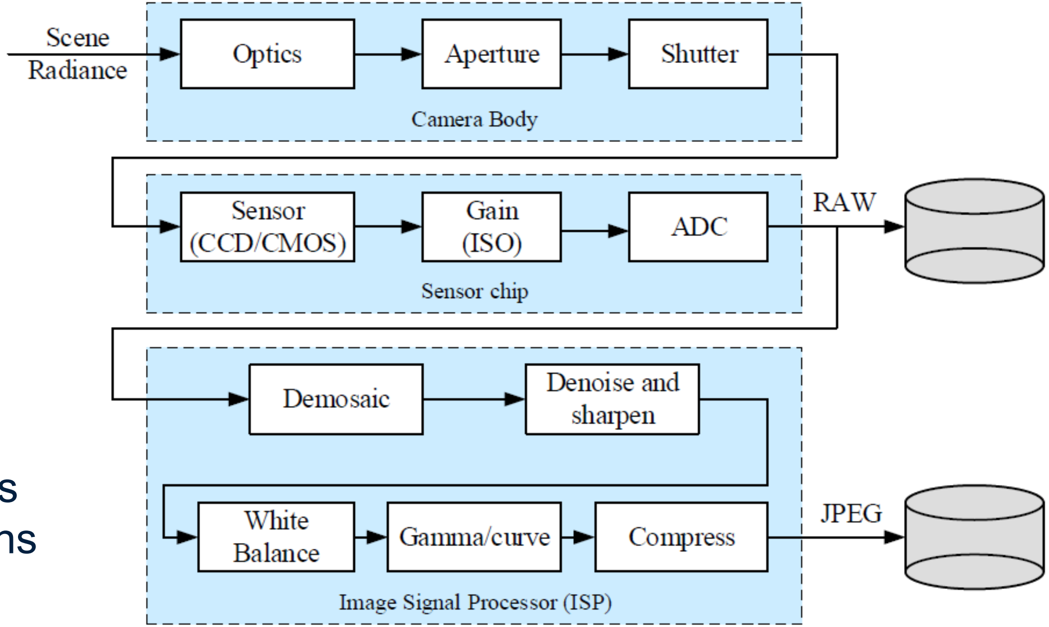
The digital camera



- Sensor chip converts photons into electrons

Why is hard? Interpreting different worlds

Jeong, J., Cho, Y., Shin, Y.-S., Roh, H., & Kim, A. (2019). Complex urban dataset with multi-level sensors from highly diverse urban environments. *The International Journal of Robotics Research*, *38*(6), 642–657. https://doi.org/10.1177/0278364919843996

239	245	255	126	7	24	0	0	0	0	0	8	9	0	0	0	0	3	0	0	0	2	0	192
254	221	34	0	16	0	0	11	8	0	0	8	5	0	0	2	0	3	0	0	0	2	0	192
208	17	0	21	0	3	9	3	0	1	1	0	0	0	1	4	0	3	0	0	0	2	0	192
99	0	0	10	0	8	0	0	9	0	0	0	9	9	0	0	0	3	0	0	0	2	0	192
192	195	196	188	190	194	192	201	191	93	8	0	4	0	0	8	0	3	0	0	0	2	0	192
255	255	255	255	255	255	255	255	255	126	10	0	7	4	0	1	0	3	0	0	0	2	0	192
128	128	128	128	128	128	128	128	123	62	6	0	1	0	0	3	0	3	0	0	0	2	0	192
0	0	0	0	0	0	0	0	8	5	2	0	0	0	0	0	0	3	0	0	0	2	0	192
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1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	12	0	7	7	0	16	188
190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	184	198	177	182	201	196	179	255

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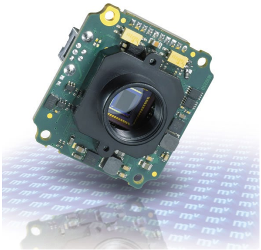
Visual Servoing – Typical Sensos



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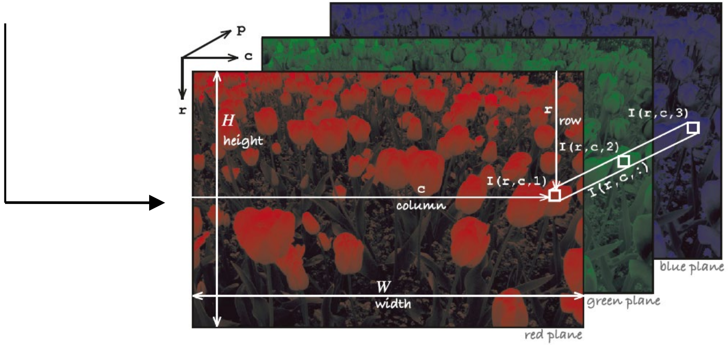
Color spaces

RGB (3 channels)

greyscale (1 channel)



other spaces
CMY
YIQ
HSI
HSV
HLS
LAB
HMMD

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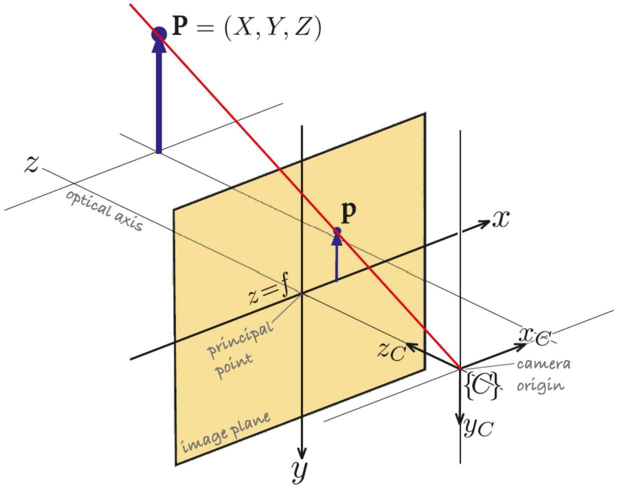
Perspective camera modelling



World coordinates: $\mathbf{P} = (X, Y, Z)$

Image coordinates: $\mathbf{p} = (x, y)$

$\mathbf{P}$ is projected to $\mathbf{p}$ through perspective projection

$$x = f\frac{X}{Z},\ y = f\frac{Y}{Z}$$

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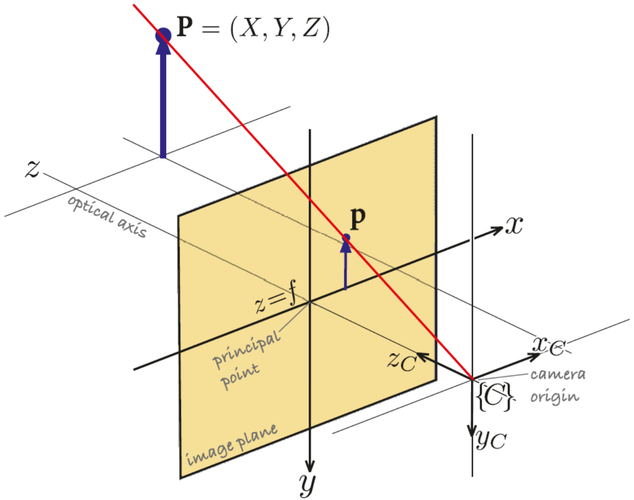
Perspective camera modelling



Homogeneous world coordinates: ${}^{C}\tilde{\boldsymbol{P}} = (X, Y, Z, 1)^T$

Homogeneous image coordinates: $\tilde{\boldsymbol{p}} = (\tilde{x}, \tilde{y}, \tilde{z})$

$$\downarrow$$

$$\tilde{x} = fX,\ \tilde{y} = fY,\ \tilde{z} = Z$$

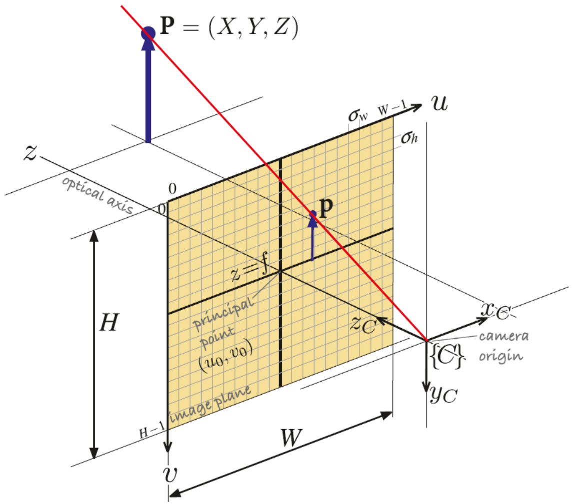
$$\downarrow$$

$$\tilde{\boldsymbol{p}} = \begin{pmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} {}^{C}\tilde{\boldsymbol{P}}$$

camera matrix C

Nonhomogeneous image coordinates: $x = \dfrac{\tilde{x}}{\tilde{z}},\ y = \dfrac{\tilde{y}}{\tilde{z}}$

Discrete image plane



pixel coordinates: $u = \dfrac{x}{\rho_w} + u_0,\ v = \dfrac{y}{\rho_h} + v_0$

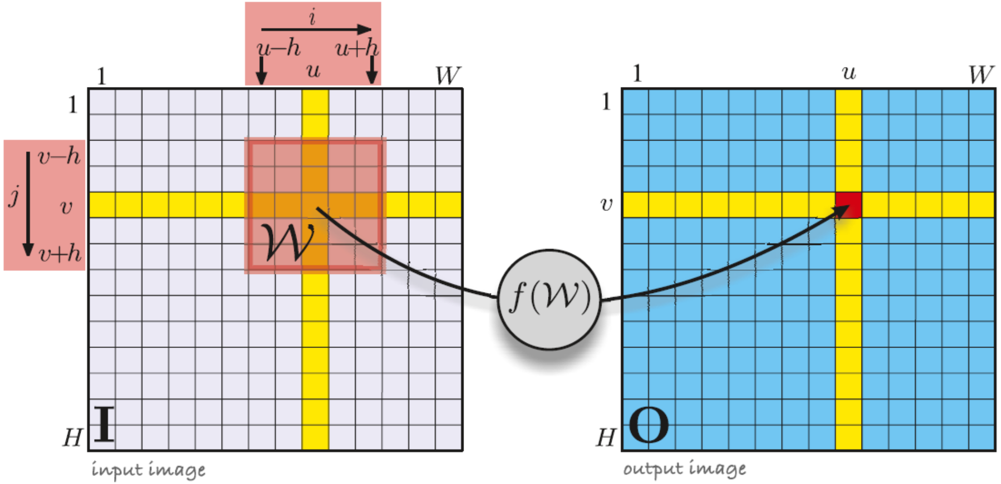
Homogeneous world coordinates: ${}^C\tilde{\boldsymbol{P}} = (X, Y, Z, 1)^T$

Homogeneous pixel coordinates: $\tilde{\boldsymbol{p}} = (\tilde{u}, \tilde{v}, \tilde{w})$

$$\tilde{\boldsymbol{p}} = \underbrace{\begin{pmatrix} 1/\rho_w & 0 & u_0 \\ 0 & 1/\rho_h & v_0 \\ 0 & 0 & 1 \end{pmatrix}}_{K} \begin{pmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} {}^C\tilde{\boldsymbol{P}}$$

Nonhomogeneous pixel coordinates: $u = \dfrac{\tilde{u}}{\tilde{w}},\ v = \dfrac{\tilde{v}}{\tilde{w}}$

Spatial Operations on Images



correlation $\longrightarrow$ $\mathbf{O} = \boldsymbol{K} \otimes \mathbf{I}$ $\longrightarrow$ $\mathbf{O}[u,v] = \sum_{(i,j)\in\mathcal{W}} \boldsymbol{I}[u+i, v+j]\boldsymbol{K}[i,j], \ \forall (u,v) \in \mathbf{I}$

convolution $\longrightarrow$ $\mathbf{O} = \boldsymbol{K} * \mathbf{I}$ $\longrightarrow$ $\mathbf{O}[u,v] = \sum_{(i,j)\in\mathcal{W}} \boldsymbol{I}[u-i, v-j]\boldsymbol{K}[i,j], \ \forall (u,v) \in \mathbf{I}$

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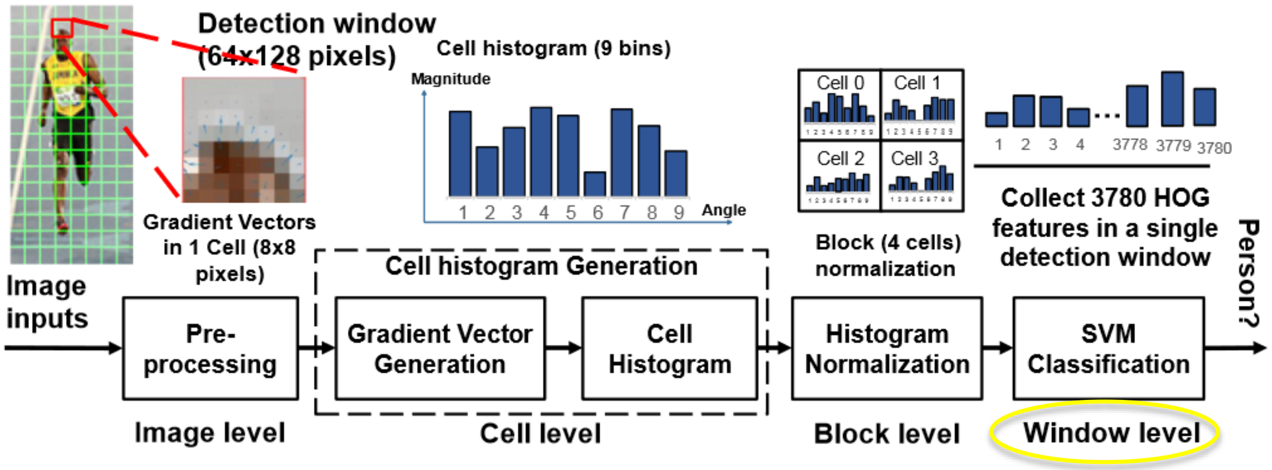
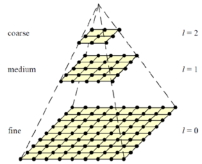
Example on Human Detection

Sliding window method

Image Pyramids





[1] Suleiman, A., & Sze, V. (2014, October). Energy-efficient HOG-based object detection at 1080HD 60 fps with multi-scale support. In 2014 IEEE Workshop on Signal Processing Systems (SiPS) (pp. 1-6). IEEE.

[2] Nguyen, N. D., Bui, D. H., & Tran, X. T. (2019, November). A novel hardware architecture for human detection using HOG-SVM co-optimization. In 2019 IEEE Asia Pacific conference on circuits and systems (APCCAS) (pp. 33-36). IEEE.

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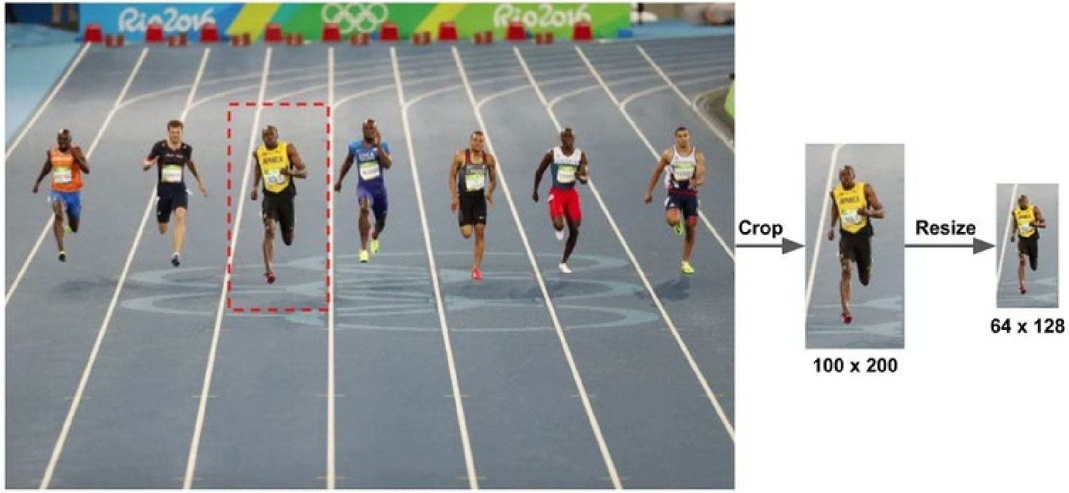
Histogram of Oriented Gradients (HOG) Descriptor

Creates a vector with histograms of directions of gradients

Step 1: Create patch of 64x128



Dalal, N., & Triggs, B. (2005, June). Histograms of oriented gradients for human detection. In 2005 IEEE computer society conference on computer vision and pattern recognition (CVPR'05) (Vol. 1, pp. 886-893). Ieee.
https://learnopencv.com/histogram-of-oriented-gradients/

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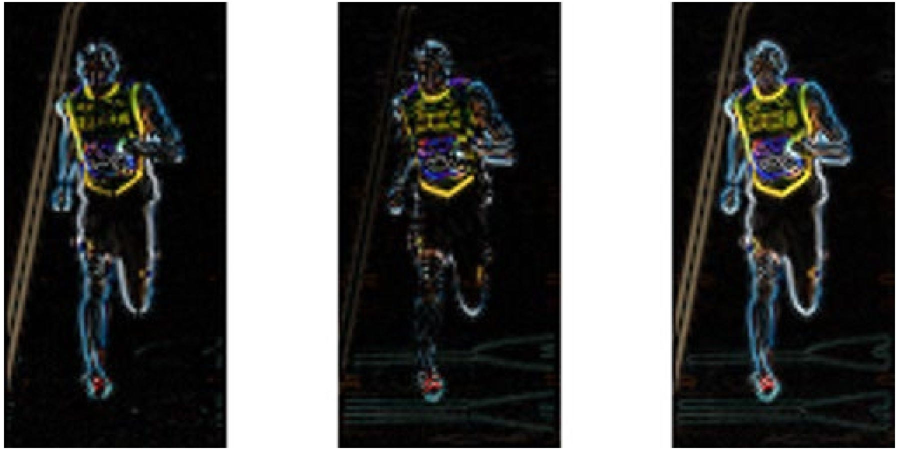
Step 2: Calculate image gradients



$$\nabla \boldsymbol{f} = \left[\frac{\partial \boldsymbol{f}}{\partial x}, \frac{\partial \boldsymbol{f}}{\partial y}\right]$$

$$M(x,y) = \|\nabla f(x,y)\| = \sqrt{g_x^2(x,y) + g_y^2(x,y)}$$

gradient magnitude

$$\alpha(x,y) = \tan^{-1}\left[\frac{g_y(x,y)}{g_x(x,y)}\right]$$

gradient direction

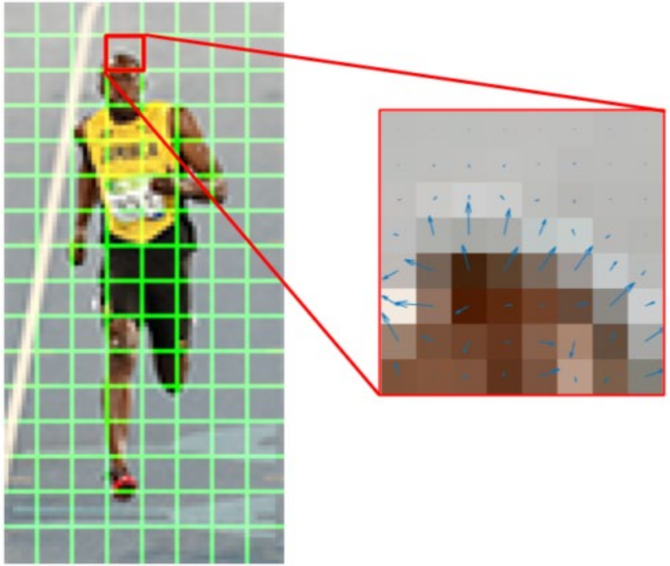
Histogram of Oriented Gradients (HOG) Descriptor

Creates a vector with histograms of directions of gradients

Step 1: Create patch of 64x128

Step 2: Calculate image gradients

Step 3: Calculate histogram of unsigned gradients in 8x8 cells



2	3	4	4	3	4	2	2
5	11	17	13	7	9	3	4
11	21	23	27	22	17	4	6
23	99	165	135	85	32	26	2
91	155	133	136	144	152	57	28
98	196	76	38	26	60	170	51
165	60	60	27	77	85	43	136
71	13	34	23	108	27	48	110

Gradient Magnitude

80	36	5	10	0	64	90	73
37	9	9	179	78	27	169	166
87	136	173	39	102	163	152	176
76	13	1	168	159	22	125	143
120	70	14	150	145	144	145	143
58	86	119	98	100	101	133	113
30	65	157	75	78	165	145	124
11	170	91	4	110	17	133	110

Gradient Direction

Histogram of Oriented Gradients (HOG) Descriptor

Creates a vector with histograms of directions of gradients

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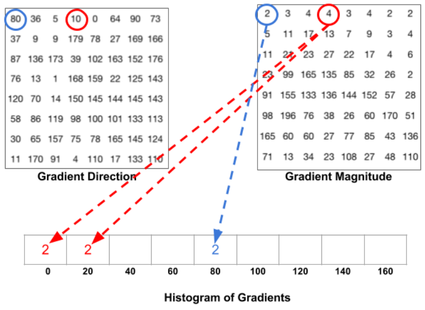
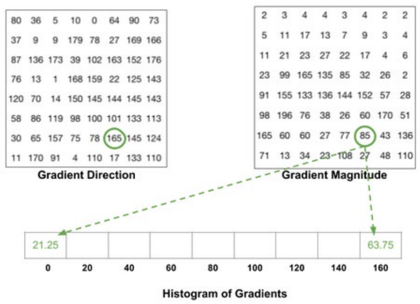
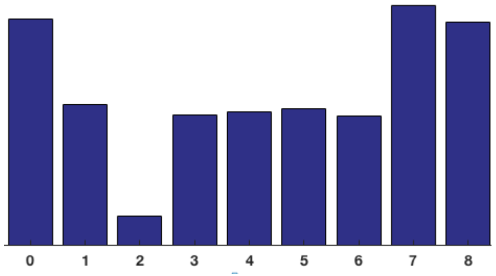
Step 2: Calculate image gradients

Step 3: Calculate histogram of gradients in 8x8 cells







Histogram of Oriented Gradients (HOG) Descriptor

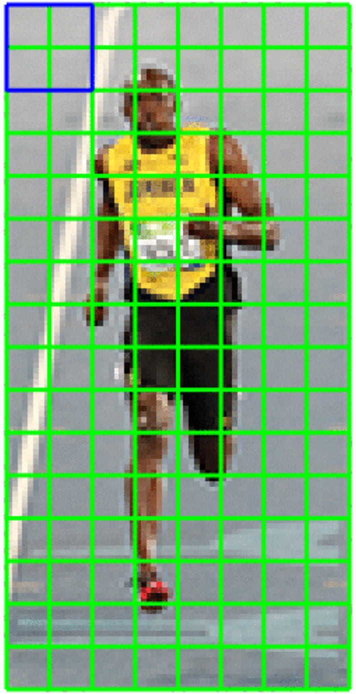
Creates a vector with histograms of directions of gradients

Step 1: Create patch of 64x128

Step 2: Calculate image gradients

Step 3: Calculate histogram of gradients in 8x8 cells

Step 4: 16x16 Block Normalization (robustness to illumination variations)



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Histogram of Oriented Gradients (HOG) Descriptor

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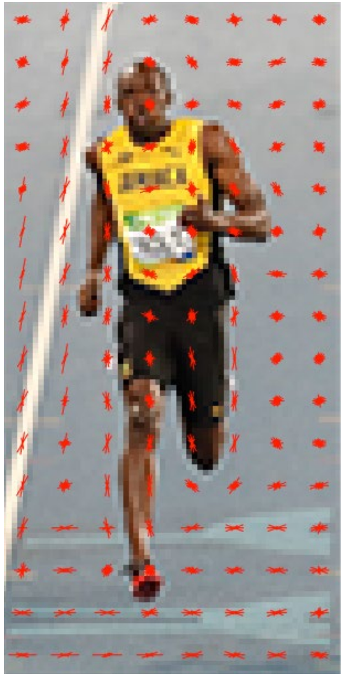

Step 5: concatenate 36x1 vectors of 7x15=105 block positions (36x105=3780 vector size)

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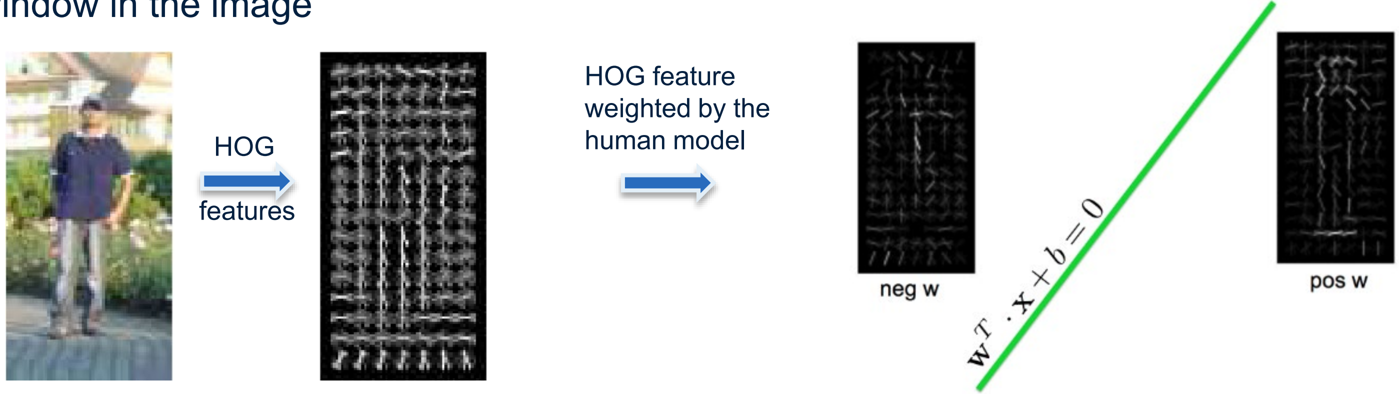
SVM Classification

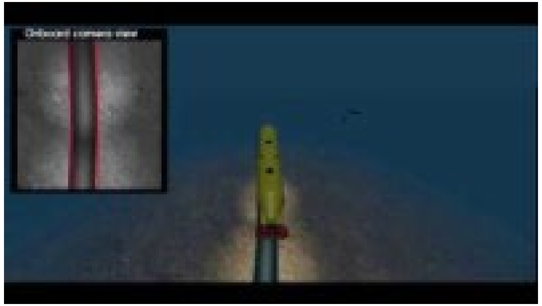
- Train a window classifier
- Use the trained classifier to predict the object class in each window in the image



Dalal, N., & Triggs, B. (2005, June). Histograms of oriented gradients for human detection. In *2005 IEEE computer society conference on computer vision and pattern recognition (CVPR'05)* (Vol. 1, pp. 886-893). Ieee.

Ahmed, A. H., Kpalma, K., & Guedi, A. O. (2017, December). Human detection using HOG-SVM, mixture of Gaussian and background contours subtraction. In 2017 13th International Conference on Signal-Image Technology & Internet-Based Systems (SITIS) (pp. 334-338). IEEE.

Focus on Vision



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Matlab Time

Break and meet during the lab time slot

```matlab
%% Matlab code D7062E

I=imread('cameraman.tif');
%%
figure,imshow(I)
%%
I_d=im2double(I);
%%
max(I(:))
%%
max(I_d(:))
%%
size(I)
%%
C=imread('autumn.tif'); %24-bit
%%
figure,imshow(C)
%%
size(C)
%%
C(100,200,2)
%%
C(100,200,:)
%%
impixel(C,200,100)
%%
imfinfo('cameraman.tif')
%% Data conversion
A =[-8.0000 4.0000 0 0.5000]
B = uint8(A)
%%
Cgr=rgb2gray(C);
%%
figure,imshow(Cgr)
%%
Cdouble=double(Cgr);
%%
```

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