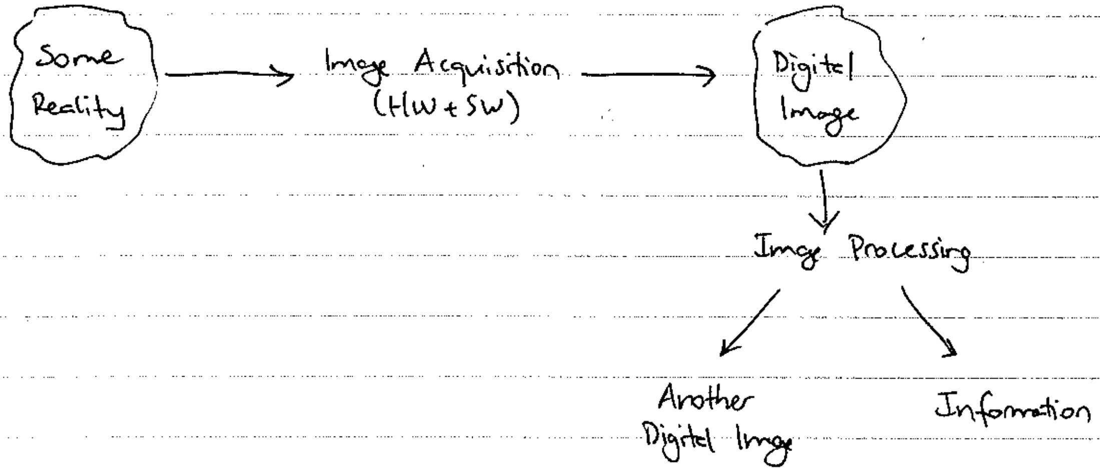
Image Processing Basics



3D world → 2D image plane (continuous)

↓ discretization

digital image

Discretization in

1. space (sampling)
2. brightness (quantization)

} resolution → picture quality

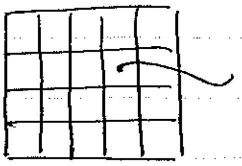
digital image: 2D array containing values from a finite set

Examples:

- Bitmaps: boolean per pixel ; $I: \mathbb{R}^2 \to \{0,1\}$ (black and white)
- Grayscale: integer per pixel ; (typical) $I: \mathbb{R}^2 \to [0,255]$
- Color: 3 integers per pixel ; $I: \mathbb{R}^2 \to [0,255]^3$
- Floating point: floating point per pixel ; $I: \mathbb{R}^2 \to \mathbb{R}_+$
  (3 floating points) ; $I: \mathbb{R}^2 \to \mathbb{R}_+^3$

  (HDR: high dynamic range images)

Color images



(c_1, c_2, c_3)

e.g. (r, g, b) — ~700 nm, ~500 nm, ~400 nm

hsi — hue (dominant wavelength), saturation (amount of dilution by white light), intensity

Image Processing Basics

Typical flow: input image → $\boxed{T}$ → output image

input image (observed) = true image + noise (adoptive noise model)

Observed Image → $\boxed{\text{Denoising}}$ → True image

Low contrast → $\boxed{\text{Contrast Enhancement}}$ → High contrast image

Large image → $\boxed{\text{Compression}}$ → Smaller image

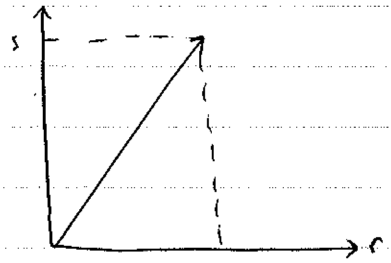
Image → $\boxed{\text{Enhancement}}$ → better looking image (to human eye)

Blurry image → $\boxed{\text{Deblurring}}$ → True image

⋮

Point operations → operations on single pixels

$$\underbrace{g(x)}_{\text{output image}} = \underbrace{T}_{\text{transformation function}}[\underbrace{f(x)}_{\text{input image}}]$$



$s = T(r)$

- r : previous value
- s : new value

e.g. Contrast streching

input image is in [0,5]

output image is in [0,50]

(Dynamic range)

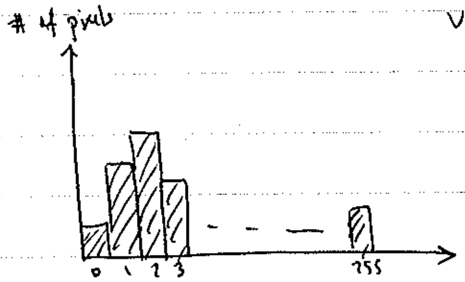
Histogram Equalization: A good quality image has a nearly uniform distribution of intensity levels

histogram: brightness distribution

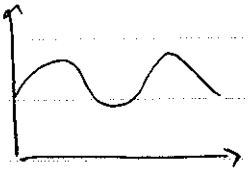
- a discrete function $h(r_k) = n_k$

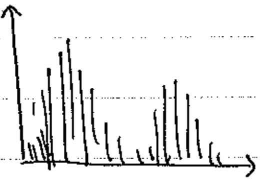
r_k: k^{th} intensity value

n_k: # of pixels in the image with intensity r_k

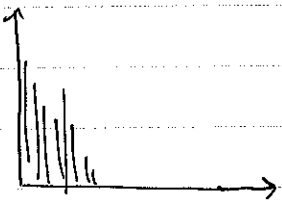


What histograms say about images?

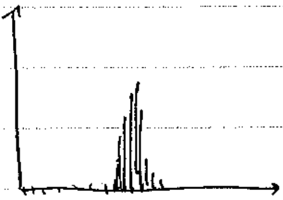




object and background



dark

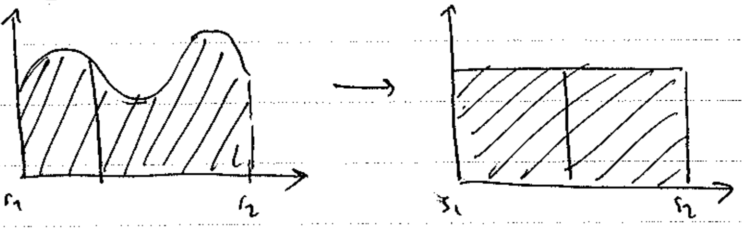


low contrast

What they don't?

- no spatial information

Histogram Equalization



All values are equally likely

Image Processing Basics

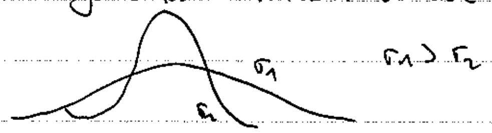
Visual Enhancement

1. **Contrast** :- a property based on human perception abilities
   - local change in brightness
   - under good conditions, we can notice a 2% change in intensity
   (Gamma correction in display devices)

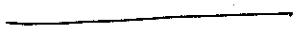
2. **Noise**: True signal + noise = observation (Additive noise model)
   - Gaussian noise: $N \sim \mathcal{N}(0, \sigma)$
   - Impulse noise
     e.g. salt/pepper noise
   - ⋮

· In Matlab,

- randn : generates a random variable from a normal distribution

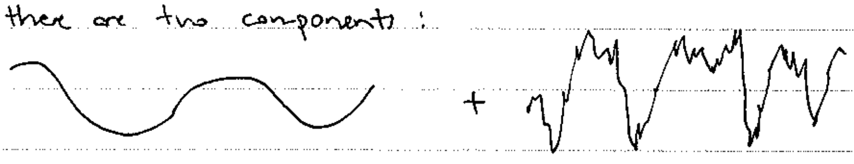


- rand : generates a r.v. from a uniform distribution



· In additive noise model,

- there are two components :



smooth/piecewise smooth
- low frequency components
  ↓ why smooth?
  neighboring pixels have similar brightness

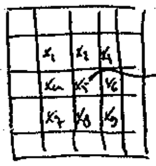
oscillating
- high frequency components
  ↓ why oscillatory?
  local changes in brightness
  - noise
  - image edges

Image Processing Basics

Arithmetic mean filter

: averaging in a neighborhood (low pass filtering)

$$\hat{f}(x,y) = \frac{1}{mn} \underbrace{\sum_{(s,t)\in S_{xy}}}_{\text{neighborhood window}} g(s,t)$$



measurement at pixel i = true value at i + noise at i

search for the true value c :

find the least-square estimate $\hat{c}$ for c

$$\min \sum_{i=1}^{N} (x_i - c)^2 \qquad N=9$$

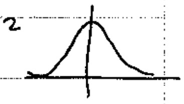
$$\Rightarrow c = \frac{1}{N} \sum x_i \quad (\text{mean})$$

weighted averaging : $\hat{f}(x,y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} w(s,t) \cdot g(s,t)$

e.g. $\begin{vmatrix} 1/16 & 2/16 & 1/16 \\ 2/16 & 4/16 & 2/16 \\ 1/16 & 2/16 & 1/16 \end{vmatrix}$ weights decay as a function of distance from the pixel of interest

Why?

e.g. select the weights from a Gaussian $\frac{1}{2\pi\sigma} e^{-\frac{1}{2\pi}(x-\mu)^2}$



(Gaussian filtering)

Median filter

$$\hat{f}(x,y) = \underset{(s,t)\in S_{xy}}{\text{median}} \{g(s,t)\}$$

$$\Rightarrow \min \sum |x_i - c|$$

(robust to outliers → salt/pepper noise)

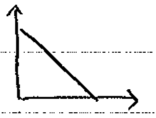
Image Processing Basics

/ /

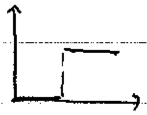
Processing Techniques:

1. Point Operations

a) Pixel based ex1: image negatives



ex2: thresholding



ex3: mid-tone enhancement

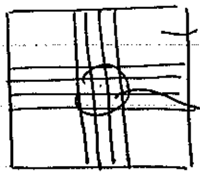
ex4: $s = \log(r)$ (dynamic range enhancement)

ex5. Gamma-correction

b) Global techniques ex1: histogram equalization

ex2: histogram matching

2. Local techniques

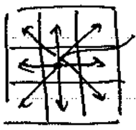


no relation

related to neighboring values

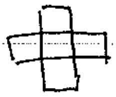
1. fixed neighborhood
2. adaptive neighborhood

Neighborhoods



p(x,y)

$N_4(p)$: 4-neighborhood



$N_D(p)$: diagonal

$N_8(p)$: $N_4(p) + N_D(p)$: 8-neighborhood

Distance measures

Let p, q, and z denote pixels with coordinates (x,y), (s,t) and (v,w), respectively

D is a distance function or metric if

i. $D(p,q) \geq 0$ ($D(p,q) = 0$ iff $p = q$) (positivity)

ii. $D(p,q) = D(q,p)$ (symmetricity)

iii. $D(p,z) \leq D(p,q) + D(q,z)$ (triangle inequality)

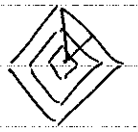
Image Processing Basics

ex1. Euclidean Distance (L_2)

$$D_{L_2}(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

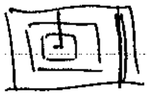
ex2. Manhattan Distance (L_1)

$$D_{L_1}(p,q) = |x-s| + |y-t|$$



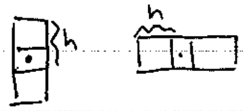
ex3. Chessboard Distance (L_∞)

$$D_{L_\infty}(p,q) = \max(|x-s|, |y-t|)$$



Edges: abrupt changes in the intensity
- → edges (some structure)
- → noise (isolated)

How to compute?
- use differentiation
- discrete derivatives



$I(x,y)$

$h=1$

$$\frac{\partial}{\partial x} I(x,y)\Big|_{ij} = \frac{I(i+h,j) - I(i-h,j)}{2h}$$

- central difference 
- Forward difference 
- Backward difference

$$\begin{bmatrix} 1 \\ \\ -1 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 1 & 1 \\ & & \\ -1 & -1 & -1 \end{bmatrix} \longrightarrow \begin{bmatrix} 1 & 2 & 1 \\ & & \\ -1 & -2 & -1 \end{bmatrix}$$

Sobel operator

Image Processing Basics

Segmentation: partitioning an image into coherent & regions

- → thresholding
- → edge-based
  - → derivative computation (to detect intensity changes)
  - → check for coherence (using direction and magnitude)
- → region-based
  - → region-growing
  - → split-merge
- → unified formulation

Today's outline

- image representation
- point operations
- histogram processing
- contrast
- intensity variation (derivative computation)
- noise
- edge / boundary
- low / high frequency
- low-pass filtering
- averaging / median
- neighborhood
- distance