ECE 418: Introduction to Image & Video Processing

Image enhancement

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Overview

1. Image enhancement
   1.1 Local enhancement
   1.2 Pseudo-color

2. Edge enhancement

3. Noise cleaning
Image enhancement
Local enhancement

Contrast is often a **local** property of the image.

- **Histogram equalization & specification** operate on the entire image.
- Sometimes it is better to enhance contrast based on **local pixel values only**.
Local enhancement

Perform point operation (histogram equalization/specification, etc.) in a small neighbourhood.

- Define a square region centered at each pixel.
- Compute the histogram within the square.
- Based on the local histogram, perform point operation on the center pixel only.
- Repeat the whole process for every pixel.
Local enhancement

Figure 1: Left: original image. Middle: Histogram equalization. Right: Local histogram equalization in 7 neighbourhood.

Fast histogram update can greatly reduce the computational complexity.

- When the square region is moved to the next pixel, only one column/row of pixels needs to be updated.
Local enhancement

Other local enhancement techniques use the local mean $\mu$ and variance $\sigma^2$ to process the image.

- Inverse contrast ratio mapping

\[ \tilde{x}(n_1, n_2) = \frac{\mu}{\sigma} \] (1)
Pseudo-color transforms a monochrome image into a color image.

- The point operation maps each grayscale value into a color, i.e. a point in 3D color space.

- Intensity slicing: Partition the grayscale range $[0, 255]$ into $M$ intervals $[l_m, l_{m+1})$, where $0 \leq m < M$, $l_0 = 0$ and $l_M = 255$.

\[
\begin{align*}
\tilde{x}(n_1, n_2) &= C_m \quad \text{if } x(n_1, n_2) \in [l_m, l_{m+1}) \quad (2) \\
\tilde{x}(n_1, n_2) &= C_M \quad \text{if } x(n_1, n_2) = 255. \quad (3)
\end{align*}
\]
Pseudo-color
Smooth curve mapping: Map every graylevels to a point on some smooth curve in the RGB space.
Full-color contrast enhancement

Color enhancement on each color component in RGB space modifies the hues and produces unpleasant results.

Figure 2: **Brightness** varies on the vertical axis, **hue** is viewed as an angle and varies along the circumference, **saturation** varies radially
Full-color contrast enhancement

Work with color coordinate systems such as HSI (hue-saturation-intensity) or YUV.

- Decouple intensity from color information (hue).
- Perform contrast enhancement on intensity image only.

For YUV, Y componenet determines the brightness of the color (luminances or luma), U and V determines the color itself.
False color

Sometimes it is desirable to change the natural color to attract the viewer’s attention.
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Edge enhancement
Edge enhancement

Sometimes it is desirable to improve the sharpness and enhance the edges in an image.

- Edges contribute significantly to high-frequency components.
Lowpass filtering

The opposite of edge enhancement is burring or lowpass filtering.

**Box (Running-average) filter**

A $N \times N$ **separable** filter as follows (when $N = 3$)

$$h(n_1, n_2) = \frac{1}{9} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

(4)

Its frequency response is the **separable** periodic sinc

$$H(\omega_1, \omega_2) = \frac{\sin(3\omega_1/2) \sin(3\omega_2/2)}{\sin(\omega_1/2) \sin(\omega_2/2)}$$

(5)
Sharpening filter

The following $N \times N$ symmetric, nonseparable filter (when $N = 3$)

$$h(n_1, n_2) = \begin{bmatrix}
-1 & -1 & -1 \\
-1 & 8 & -1 \\
-1 & -1 & -1 \\
\end{bmatrix}$$

- This filter has zero DC response: $H(0, 0) = 0$.
- It could create negative values.
- Scaling and clipping is needed after filtering so that the values $\in [0, 255]$. 

## Edge enhancement

### High-frequency emphasis

$$h(n_1, n_2) = \begin{bmatrix} -1 & -1 & -1 \\ -1 & w & -1 \\ -1 & -1 & -1 \end{bmatrix}$$  \hspace{1cm} (7)

- When $w = 9$, it has DC response $H(0, 0) = 1$. Its performance is often satisfactory.
- Known as *unsharp masking* in printing and publishing business.

- Contrast enhancement (point operation) and highpass filtering (spatial operation) are often combined to enhance edges.
Noise cleaning
Noise cleaning

Digital images are often corrupted by noise from several sources (sensor noise, etc.)

- It’s desirable to remove as much noise as possible without degrading the image itself.
- We rely on prior knowledge about the nature of the image to discriminate between image and noise.
Assume the clean image $x(n_1, n_2)$ is corrupted by additive noise $w(n_1, n_2)$

$$y(n_1, n_2) = x(n_1, n_2) + w(n_1, n_2)$$  

(8)

Take DSFT and let $f_1 = \omega_1 / 2\pi$, $f_2 = \omega_2 / 2\pi$

$$Y(f_1, f_2) = X(f_1, f_2) + W(f_1, f_2)$$  

(9)
Lowpass filtering

Adjacent pixels of the noise $w(n_1, n_2)$ often have wildly different values

- Noise contain significant high-frequency component.

Image energy is mostly concentrated at low frequency.

- Lowpass filtering should reduce noise considerably, and affect image contents just slightly.
Lowpass filtering

Let $f_1 = \omega_1 / 2\pi$ be the normalized frequency, we can show the magnitude of the frequency response of a 1D block filters

![Graph of frequency response of the moving average filter. The moving average is a very poor low-pass filter, due to its slow roll-off and poor stopband attenuation. These curves are generated by Eq. 15-2.]

- The main lobe width is $\frac{1}{N}$, it can be considered to be a cutoff frequency.
- The cutoff frequency should be chosen carefully to balance two conflicting goals: Remove noise and preserving image integrity.
Spatial domain interpretation: For the 3 box filter, after filtering the locally averaged noise is

$$\frac{1}{9} \sum w(n_1, n_2)$$

(10)

- If the noise is uncorrelated, the noise variance is reduced by a factor 9.
- It would be even better if the noise has zero mean.
Lowpass filter design

Sinc (Brick wall) filter

1D brick wall filter

\[ h(t) = 2B \text{sinc}(2Bt) \]  \hspace{1cm} (11)

\[ H(f) = \text{rect}\left(\frac{f}{2B}\right) \]  \hspace{1cm} (12)

2D brick wall filter: \( h(n_1, n_2) = h(n_1)h(n_2) \)

Figure 4: Left: A 1D sinc filter \( h(t) \); Right: its frequency response
Lowpass filter design

Sinc filter has disadvantages:

- The length of the filter is long.
- Ringing artifacts around the vicinity of edges.

Short FIR filter

Design the filter such that

- Computational economy.
- Each pixel value is determined by other pixels in a small neighbourhood, rather than distant, unrelated parts of the image.
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