# EE421/521 Image Processing

Lecture 11a
BLUR IDENTIFICATION

1

## *Introduction*

2

## Estimation of Filter Parameters

- Blur estimation
- Image power spectrum estimation
- Noise power spectrum estimation

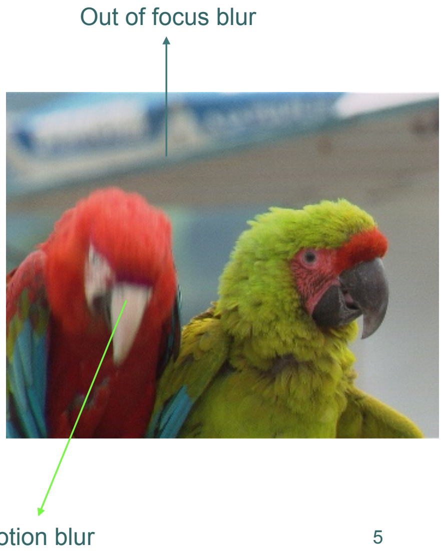
3

## Sources of Blur

- Out-of-focus camera
- Relative motion between the camera and the scene
- Atmospheric turbulance (random fluctuations of the refraction index of the medium)

4

# Examples


5

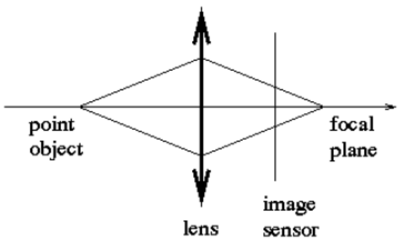
# Example: Atmospheric Turbulance

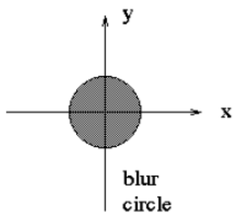
6

# Point Spread Function (PSF) for Out-of-focus Blur

- Definition: Point Spread Function
  - The image h(m,n) of a point object δ(m,n)
- Out-of-focus blur

$$h(x_1,x_2)=\begin{cases}\dfrac{1}{2\pi R^2} & \text{if } x_1^2+x_2^2\le R^2\\ 0 & \text{otherwise}\end{cases}$$



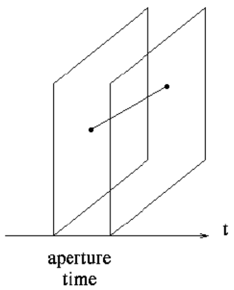

7

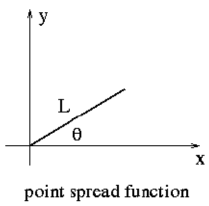
# PSF for Linear Motion Blur

- Linear Motion Blur

$$h(x_1,x_2)=\begin{cases}\dfrac{1}{L} & \text{if } -\dfrac{L}{2}\le x_1\le\dfrac{L}{2} \text{ and } x_2=0\\ 0 & \text{otherwise}\end{cases}$$

Arbitrary linear motion




Horizontal motion

h(x)


8

# LSI Blur Modeling

- (E.g. Whole image is out-of-focus)

(Blurred image) $g_k(n_1,n_2) = h_k(n_1,n_2) ** s_k(n_1,n_2) + v_k(n_1,n_2), k = 1,\ldots,L$ (ideal image: $s_k$)

$$h_k(n_1,n_2) = h(n_1,n_2) \quad \text{(same for each frame)}$$

- In vector-matrix form

$$\underline{g}_k = \underline{\underline{D}}_k \underline{s}_k + \underline{v}_k$$

$\underline{g}_k$: $N^2 \times 1$; $\underline{\underline{D}}_k$: $N^2 \times N^2$; $\underline{s}_k$: $N^2 \times 1$

- In the frequency domain

$$G_k(w_1,w_2) = H_k(w_1,w_2)S_k(w_1,w_2) + V(w_1,w_2)$$

9

# LSV Blur Modeling

- The PSF function is different for different parts of the image (e.g., part of the image is out-of-focus)

$$h_k(n_1,n_2;i_1,i_2) = L_k\{\delta(n_1 - i_1, n_2 - i_2)\}$$

$$g_k(n_1,n_2) = \sum_{(i_1,i_2)\in S} s_k(i_1,i_2)h_k(n_1,n_2;i_1,i_2) + v_k(i_1,i_2)$$

10

# Blur Identification Methods

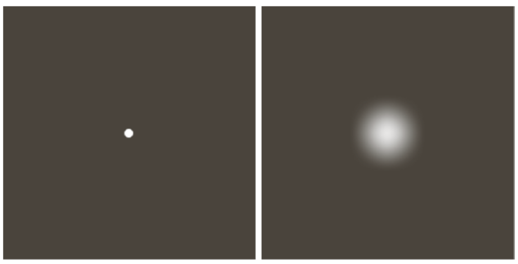
- Ad-hoc methods
  - Trial and error
  - Using points or sharp lines in the image
- Autocorrelation method
- Spectral methods
  - Finding zero crossings of Log-power spectrum
  - Finding peaks in the cepstrum

11

# Using a Point Source

a b

**FIGURE 5.24** Degradation estimation by impulse characterization. (a) An impulse of light (shown magnified). (b) Imaged (degraded) impulse.



12

## Auto-correlation Method

$$g(n) = h(n) * s(n)$$

$$r_g(n) = \sum_i g(i)g(i+n) = \sum_i \sum_k h(k)x(i-k) \sum_l h(l)x(i+n-l)$$

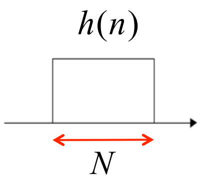
$$r_g(n) = \sum_l h(l) \sum_k h(k) \underbrace{\sum_i x(i-l)x(i+n-k)}_{\approx \delta(l+n-k)}$$

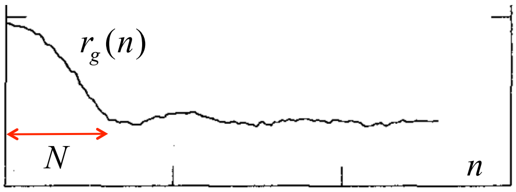
$$r_g(n) \approx \sum_l h(l)h(l+n)$$

13

## Auto-correlation Method: 1-D Motion Blur

$$r_g(n) \approx \sum_l h(l)h(l+n)$$

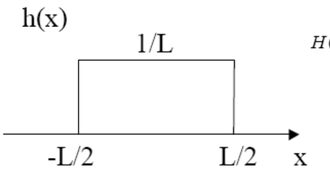


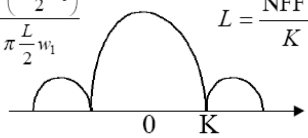

14

# Spectral Methods

- Spectrum of Linear Motion Blur

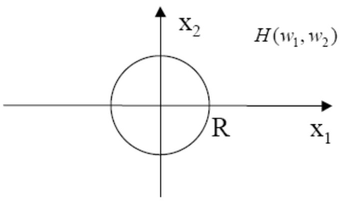



$$H(w_1,w_2)=\frac{\sin\left(\pi\frac{L}{2}w_1\right)}{\pi\frac{L}{2}w_1}$$

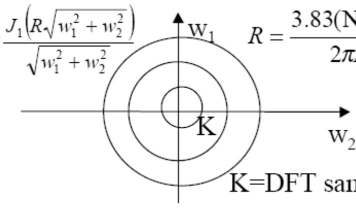



$$L=\frac{\text{NFFT}}{K}$$

- Spectrum of Out-of-Focus Blur




$$H(w_1,w_2)=2\pi R\frac{J_1\left(R\sqrt{w_1^2+w_2^2}\right)}{\sqrt{w_1^2+w_2^2}}$$



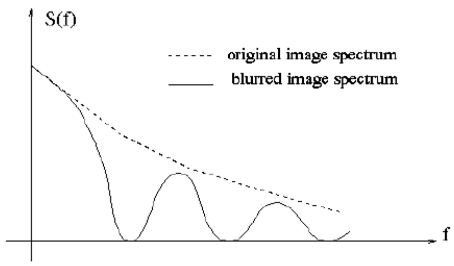

$$R=\frac{3.83(\text{NFFT})}{2\pi K}$$

K=DFT sample

15

# Power Spectrum of the Blurred Image

$$S_{b_e}(w_1,w_2)=\left|H(w_1,w_2)\right|^2 S_{s_e}(w_1,w_2)$$




Assumptions:

- The blur transfer function has regular zero-crossings.
- The undegraded image spectrum does not have zero-crossings.
- The signal-to-noise ratio is high enough.

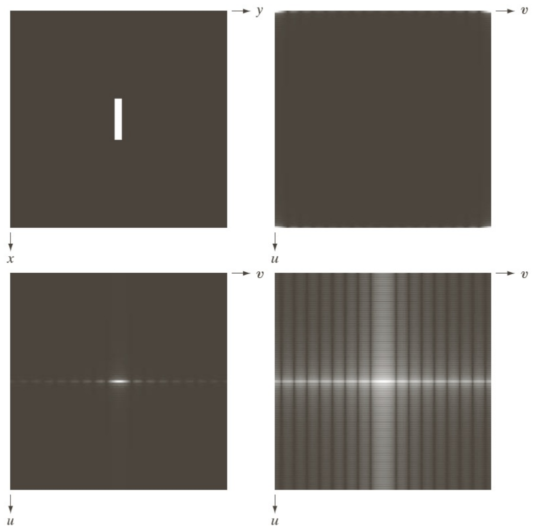
16

# Log-Power Spectrum Method

- Spectral estimation $S_g(w_1,w_2)$
  - Divide the image (intensity domain) into N×N blocks (typically N=128)
  - Compute $|G_k(w_1,w_2)|^2$ over each block
  - Compute the average of the results
- Compute log $S_g(w_1,w_2)$
  - the zeros of the power spectrum are mapped to minus infinity
- Detect the DFT sample where the first zero of the power spectrum occurs

17

# Log-Power Spectrum Method

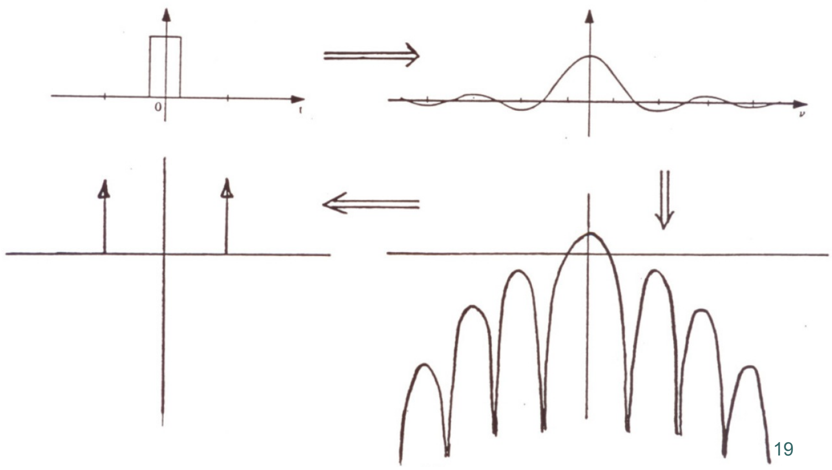



a b
c d

**FIGURE 4.24** (a) Image. (b) Spectrum showing bright spots in the four corners. (c) Centered spectrum. (d) Result showing increased detail after a log transformation. The zero crossings of the spectrum are closer in the vertical direction because the rectangle in (a) is longer in that direction. The coordinate convention used throughout the book places the origin of the spatial and frequency domains at the top left.

18

# Cepstral Method





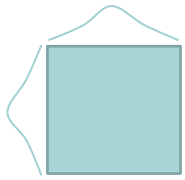
# Image Power Spectrum Estimation

Divide the image into NxN blocks

# Power Spectrum Estimation

- Apply Hanning window to all blocks

$$w[n,m] = \begin{cases} (0.5 + 0.5\cos(\pi n/N))(0.5 + 0.5\cos(\pi n/N)) & -N \le n,m \le N \\ 0 & elsewhere \end{cases}$$



21

# Power Spectrum Estimation

- Calculate the 2D DFT of all windowed blocks and compute the power spectrum of the observed image as

$$P_g(k,l) = \frac{1}{M} \sum_i \sum_j \left| DFT\{g_{ij}\} \right|^2$$

- where $g_{ij}$ denotes a block and $M$ is the total number of blocks.

22

# Noise Power Spectrum Estimation

Use the same steps to compute the noise power spectrum, however, use only blocks with uniform intensity.




# Noise Variance Estimation

- Calculate the variance of each uniform block and average over the blocks.
- Use this variance value as the power spectrum of the noise (flat spectrum: white noise)

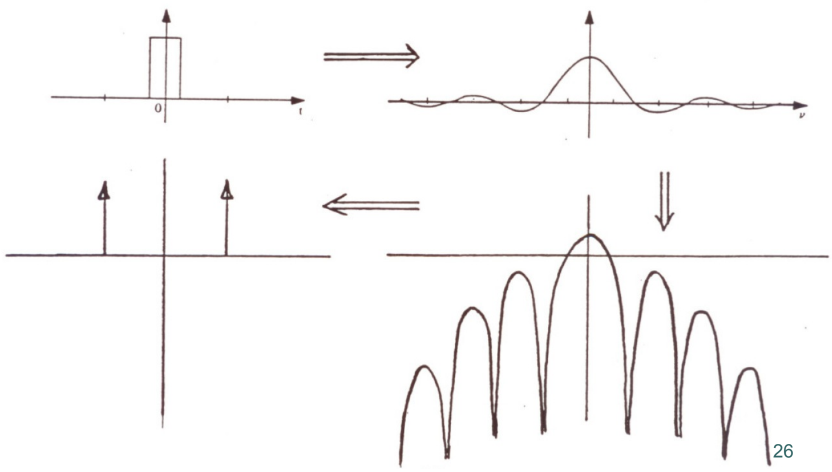
# *Project 3.2a*

Blur Identification

*Due 29.12.2013 Sunday*

25

## Blur Identification



26

# Problem 3.2a

- Select an arbitrary monochrome MxN image and display it.
- Blur each line of the image with a 15x1 horizontal motion blur. Display the blurred image.
- Obtain the 1-D power spectrum of the blurred image using the following equation (n denotes the line number, M denotes the total number of lines). make sure to apply a Hanning window to each line before taking the DFT. Plot the resulting 1-D power spectrum.

$$P_g(k) = \frac{1}{N} \sum_n \left| DFT_M \{g_n\} \right|^2$$

- Identify the zeroes of the 1-D power spectrum by inspection.
- Calculate the 1-D cepstrum by taking the inverse DFT of the logarithm of the 1-D power spectrum. Plot the 1-D cepstrum.
- Identify the first peak in the 1-D cepstrum (a) by inspection (b) with a computer program.
- Report and comment on your results.

27

# Next Lecture

- IMAGE RESTORATION

28