光画像工学
Optical imaging and image processing

1

Optical imaging and image processing

Autumn and winter semester, Units: 2-0-0
Professor Masahiro Yamaguchi
Objective
Based on the knowledge of the diffraction and interference of light, optical imaging theory, and two-dimensional Fourier transform, the fundamentals of optical imaging systems and digital image processing are described. The applications in image analysis, restoration and reconstruction are also introduced.
References
J. W. Goodman, "Introduction to Fourier Optics," McGraw-Hill (New York)
W. K. Platt, "Digital Image Processing," John Wiley & Sons
Also,
A. Rosenfeld and A. C. Kak, "Digital Picture Processing," 2nd Edition, Vol.1, 2, Academic Press, Inc
Prerequisite
Students are recommended to take "Fundamentals of Digital Signal Processing" before taking this class. (Not mandatory)
Evaluation: Homework and in-class exercises, Short exams (twice), class attendance
Note
The class in 2012 is given in English.
Send e-mail for appointment.

2

Course Schedule

2012/10/2 1. Introduction
2012/10/16 2. Basics of imaging systems (1)
Linear system, Impulse response, Fourier transform, Transfer function, Statistical characterization
2012/10/23 3. Basics of imaging systems (2)
Image sampling, interpolation, discrete Fourier transform
2012/10/30 4. Optical imaging systems (1)
Wave optics, Diffraction, Imaging through a lens system
2012/11/6 5. Optical imaging systems (2)
Resolution of optical imaging system
2012/11/13 6. Optical imaging systems (3)
Geometrical optics, Ray-tracing, Lens aberration, Optical imaging devices
2012/11/20 7. Image restoration,
2012/11/27 8. Image reconstruction, computational imaging
2012/12/4 9. Color imaging (1)
Color spaces, Color reproduction
2012/12/11 TBA
2012/12/18 10. Color imaging (2)
Color image processing
2013/1/8 11. Multispectral Imaging
2013/1/15 12. Three-dimensional imaging
2013/1/22 13. Three-dimensional display
2013/1/29 14. Holography
2013/2/12 15. Makeup class / Short exam.

4

What we will learn in this course

- Theoretical background of optical and digital image acquisition, processing, and display systems.
  - Ex. Digital Still Camera, Camcoder, Digital Television, Video systems, Image scanner, Displays, Printers, Microscopy, Optical measurement, Stereoscopic displays, holography
  - Imaging through lens system, Color imaging, Multispectral imaging, 3D imaging
- Keys to the typical techniques used in historical and latest image processing systems.
- Some recent R&D topics in optical imaging and image processing.

What we will NOT learn in this course:

- Details of image processing methods used in the practical imaging systems.
- Hardware implementation methods of digital image processing.
- Some nonlinear techniques; binary image processing, morphological image processing, ...
- Image coding and decoding methods.

5

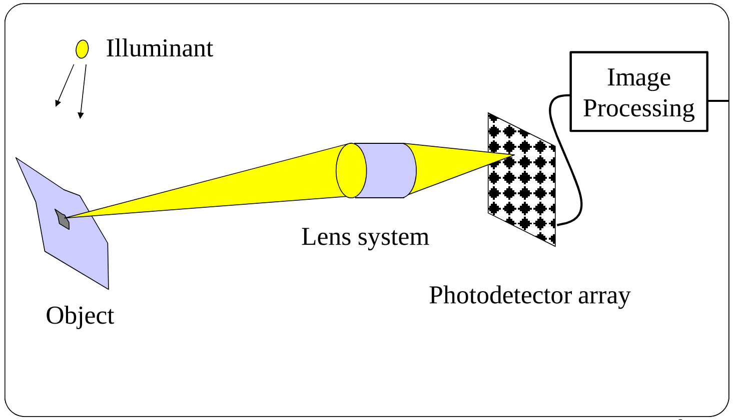
1. Basics of imaging systems

- Introduction
- Linear imaging systems
- Mathematical characterization of images
- Fourier transform and imaging system
- Linear operators
- Image acquisition and digitization

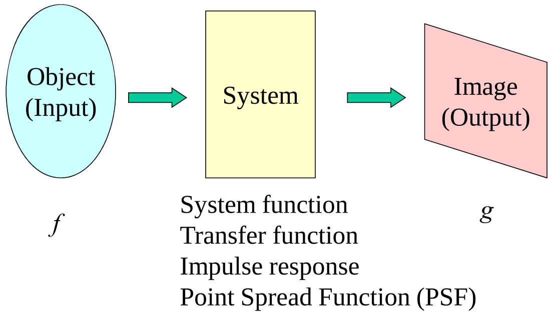
1.1 Introduction

- Scope of this class
  - Linear imaging system
  - Linear, space-invariant imaging system
  - Imaging through lens system
  - Image processing system
  - Image restoration, reconstruction
  - Color imaging
  - 3D imaging

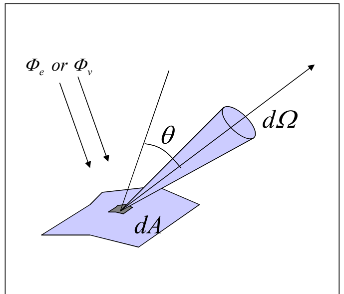
What is an imaging system?



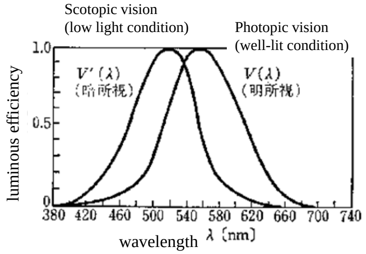
General model of imaging systems



1.2 Radiometry and Photometry
1.2 放射量と測光量



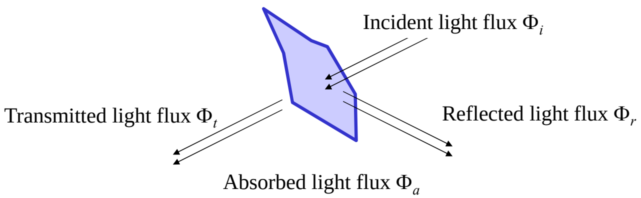
Emission or radiation at a surface



V(λ): Spectral luminous efficiency of human vision
分光視感効率 （比視感度）

Maximum luminous efficacy @555nm
$K_m = 683\ \mathrm{lm \cdot W^{-1}}$
最大視感度

Reflection, transmission, and absorption
光の反射, 透過, 吸収



$$\Phi_i = \Phi_r + \Phi_t + \Phi_a$$

反射率, 透過率

Reflectance: $\rho = \dfrac{\Phi_r}{\Phi_i}$

Transmittance: $\tau = \dfrac{\Phi_t}{\Phi_i}$

Optical density (**光学濃度**)

Reflectance density: $D_\rho = -\log_{10}\rho = \log_{10}\dfrac{\Phi_i}{\Phi_r}$

Transmittance density: $D_\tau = -\log_{10}\tau = \log_{10}\dfrac{\Phi_i}{\Phi_t}$

(Optical densities)

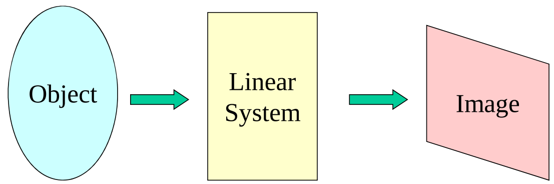
Radiant and luminous quantities

- Radiant quantities: physical
- Luminous quantities: psychophysical, related to the stimuli to the human vision

Radiant quantities		Definition	Unit	Luminous quantities		Definition	Unit
Radiant Energy	Q_e	Energy emitted or transmitted from an object	J	Quantity of light	Q_v	$\int \Phi_v dt$	lm·s
Radiant flux	Φ_e	$\dfrac{dQ_e}{dt}$	W	Luminous flux	Φ_v	$K_m \int \Phi_e(\lambda) V(\lambda) d\lambda$	lm
Radiant exitance	M_e	$\dfrac{d\Phi_e}{dA}$	$\mathrm{W \cdot m^{-2}}$	Luminous exitance	M_v	$\dfrac{d\Phi_v}{dA}$	$\mathrm{lm \cdot m^{-2}}$
Irradiance	E_e	$\dfrac{d\Phi_e}{dA}$	$\mathrm{W \cdot m^{-2}}$	Illuminance	E_v	$\dfrac{d\Phi_v}{dA}$	lx
Radiant intensity	I_e	$\dfrac{d\Phi_e}{d\Omega}$	$\mathrm{W \cdot sr^{-1}}$	Luminous intensity	I_v	$\dfrac{d\Phi_v}{d\Omega}$	cd
Radiance	L_e	$\dfrac{d^2\Phi_e}{dA d\Omega \cos\theta}$	$\mathrm{W \cdot m^{-2} \cdot sr^{-1}}$	Luminance	L_v	$\dfrac{d^2\Phi_v}{dA d\Omega \cos\theta}$	$\mathrm{cd \cdot m^{-2}}$

Ex., 40W Fluorescent Lamp: Quantity of light ≅ 3000 lm, Luminance ≅ 9000 $\mathrm{cd \cdot m^{-2}}$
Normal desktop irradiance ≅ 300lx
Luminous intensity of x W Incandecent lamp ≅ x cd

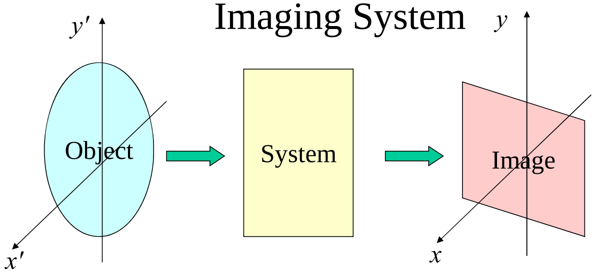
1.2 Linear Imaging System



System function
Transfer function
Impulse response
Point Spread Function (PSF)

$$g(x, y) = \iint h(x, y; x', y') f(x', y') dx' dy'$$

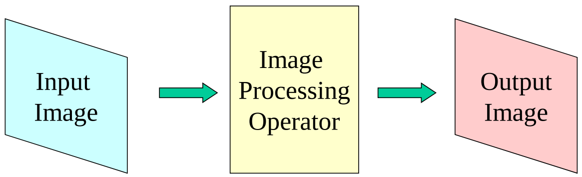
Linear, shift-invariant Imaging System



$$g(x,y) = \iint h(x-x', y-y') f(x', y') dx' dy'$$
$$= f(x,y) * h(x,y)$$

$$G(u,v) = H(u,v) F(u,v)$$

Image Processing System

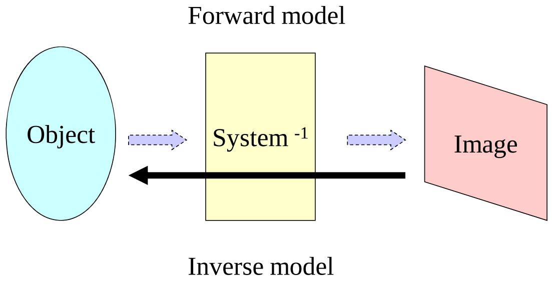


Linear, shift-invariant filtering

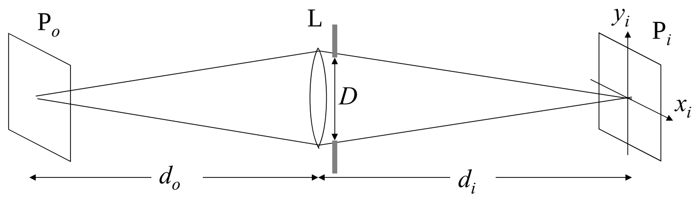
$$g(x,y) = \iint h(x-x', y-y') f(x', y') dx' dy'$$
$$= f(x,y) * h(x,y)$$

$$G(u,v) = H(u,v) F(u,v)$$

Image restoration, reconstruction



Imaging through lens system



画像のぼけ Image blur
- **焦点はずれ** Defocus
- **レンズの収差** Lens aberration
- **回折限界** Diffraction limit
- **検出器の開口** Sampling aperture

サンプリング Sampling

歪 Distortion

ノイズ Noise

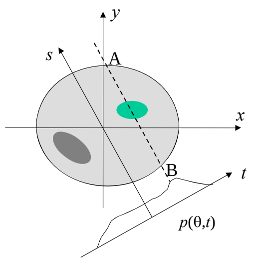
Computed Tomography

X-ray absorption coefficient distribution $f(x,y)$

Observed X-ray intensity $I(\theta,t)$

Observed X-ray intensity when no object present $I_0(\theta,t)$

Projection data $p(\theta,t)$



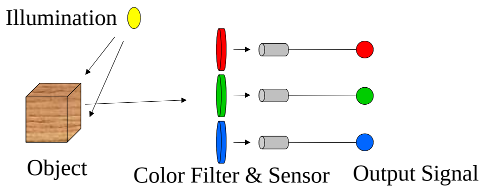
$$I(\theta,t) = I_0(\theta,t)\exp\{-\int_{AB} f(x,y)ds\}$$

$$p(\theta,t) = -\log\{I(\theta,t)/I_0(\theta,t)\} = \int f(t,s)ds$$

$$\begin{bmatrix} t \\ s \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

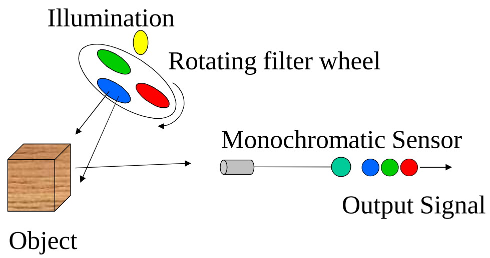
$$p(\theta,t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x\cos\theta + y\sin\theta - t)dxdy$$

Color image sensor



$$g_j = \int E(\lambda)S_j(\lambda)f(\lambda)d\lambda$$

Time-sequential color image sensor



$$g_j = \int E_j(\lambda)S(\lambda)f(\lambda)d\lambda$$

Homework: Questions 1

(1) What is the difference of luminance and radiance?

(2) Discuss briefly on what kind of radiant or luminous quantity is captured by the pixels values of black/white cameras.

(3) What is the reflectance of a printed material of the optical density = 1.0?

Till next week