Fundamentals

**Delivered by**

**Dr. Subarna Chatterjee**

**subarna.cs.et@msruas.ac.in**

1 

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Text Book

**a. Essential Reading**

1. Gonzalez and Woods. (2009) Digital Image Processing, 3rd Edition, Prentice Hall 2. Chanda Bhabatosh and Majumder Dwijesh. (2009) Digital Image Processing and Analysis, PHI Willis J.

3. M. C. Bishop, 2006, Pattern Recognition and Machine Learning, Springer 4. S. Theodoridis, K. Koutroumbas, 2008, Pattern Recognition, Academic Press. **b. Recommended Reading**

1. Bernd Jahne. (2005) Digital Image Processing, Springer, 6th Edition 2. Stephane Maarchand Maillet and Yazid M. Sharaiha. (2000) Binary Digital Image Processing: A Discrete Approach, Academic Press

3. R. Szeliski, 2010, Computer Vision: Algorithms and Application, Springer-Verlag Inc. 4. D. A. Forsyth, J. Ponce, 2003, Computer Vision: A Modern Approach, Pearson Education **c. Online Tutorial**

1. https://nptel.ac.in/courses/117/105/117105135/

2

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Digital Image Fundamentals

• Human visual system

• A simple image model

• Sampling and quantization

3

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Human Visual System

• Brightness adaptation

• Brightness discrimination

• Weber ratio

• Mach band pattern

• Simultaneous contrast

4

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Human Visual System

• Elements of visual perception

The amount of light entering the

eye is controlled by the pupil, which

dilates and contracts accordingly.

The cornea and lens, whose shape

is adjusted by the ciliary body,

focus the light on the retina, where

receptors convert it into nerve

signals that pass to the brain.

5

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Human Visual System

• Elements of visual perception

– **Cones**

• 6 – 7 million in each eye

• Photopic or bright-light vision

• Highly sensitive to color

– **Rods**

• 75 – 150 million

• Not involved in color vision

• Sensitive to low level of illumination (scotopic or dim-light vision)

– An object appears brightly colored in daylight will be seen colorless in moonlight (why)

6

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Visual Perception

• Image formation in the eye(Pinhole Camera Model) – Distance between center of lens and retina (focal length) vary between 14-17 mm.

– Image length h = 17(mm) x (15/100)

15 / 100 = h / 17 

⇒h = 2.55 mm

Faculty of Engineering & Technology

focal length (min.

refractive power)

7

© Ramaiah University of Applied Sciences

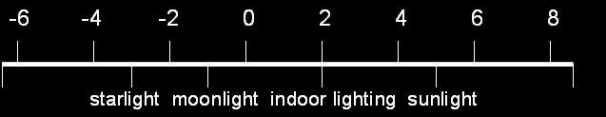
Human Visual System

• Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye

• The electromagnetic spectrum is split up according to the wavelengths of different forms of energy

Human simultaneous luminance vision range

(5 orders of magnitude)

log (cd/m2) 8

Faculty of Engineering & Technology

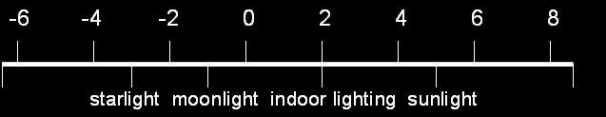
© Ramaiah University of Applied Sciences

Human Visual System



Human simultaneous luminance vision range

(5 orders of magnitude)

log (cd/m2) 9

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• Brightness adaptation in the Human Eye – HVS can adapt to light intensity range on the order of 1010

– human eye can adapt over 10 orders of magnitude!

▪ 6 orders in phototopic vision (cones)

▪ accomplished by brightness adaptation (changes in the overall sensitivity)

▪ much smaller range for each brightness adaptation level ����

– Subjective brightness is a log function of the light intensity incident on the eye

– brightness discrimination

▪ poor at low levels of illumination 

▪ better with increasing illumination

Faculty of Engineering & Technology

10 © Ramaiah University of Applied Sciences

Human Visual System

• **Brightness adaptation**

– The HVS cannot operate on such range (10 orders of magnitude) simultaneously

– It accomplishes this through (brightness) adaptation

– The total intensity level the HVS can discriminate simultaneously is rather small in comparison (about 4 orders of magnitude)

11

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Human Visual System

• Brightness adaptation

For a given

observation

condition, the

Sensitivity of the HVS

for the given

adaptation level

Anything below Bb will

be perceived as

indistinguishable

blacks

Faculty of Engineering & Technology

current sensitivity level is call the

brightness

adaptation level

© Ramaiah University of Applied Sciences

12

Cont..

• Brightness discrimination



• Perceivable changes at a given adaptation level

– The **ratio** of increment of illumination to background of illumination is called as. **weber ratio**.(ie) ∆i/i.

• If the **ratio** (∆i/i) is small, then small percentage of change in intensity is needed. (i.e) good brightness adaptation.

• If the ratio (∆i/i) is large , then large percentage of change in intensity is 13 

needed (i.e) poor brightness adaptation.

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Visual Perception

• Perceived brightness is not a simple function of intensity – Mach band pattern

• stripes appear darker

near a more intense

stripe (and vice versa)

• caused by inhibitory

neural connections

14

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Visual Perception

• Perceived brightness is not a simple function of intensity – Mach band pattern

• stripes appear darker

near a more intense

stripe (and vice versa)

• caused by inhibitory

neural connections

– simultaneous contrast

• a regions perceived

brightness depends

on the intensity in

the neighbor hood

15

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Human Visual System

• Perceived brightness is not a simple function of intensity – Simultaneous contrast



16

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Sensation vs Perception

• Sensation

– operation of basic sensory systems

– result of physical stimuli and low-level processes

• Perception

– involve higher-level processes in the percipient

– memories

– Expectations

– Emotions

– state of fatigue or alertness

17

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• Image Formation in the Human Eye

– perceived brightness is not a simple function of intensity! o Mach bands

▪ stripes appear darker near a more intense stripe (and vice versa)

▪ caused by inhibitory neural connections

o simultaneous contrast

▪ a regions perceived brightness depends on the intensity in the

neighborhood

– optical illusions

18

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Optical Illusions

• Optical Illusions

– the eye / brain fills in non existing information

– perceives geometrical properties of an object wrongly 

– characteristic of the human visual system and not yet fully understood ...

19

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Optical Illusions

• movement created only in the brain



20

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont.. 

• In Fig. 2.9(a), the outline

of a square is seen

clearly, despite the fact

that no lines defining

such a figure are part of

the image. The same

effect, this time with a

circle, can be seen in Fig.

2.9(b); note how just a

few lines are sufficient to

give the illusion of a

complete circle. The two

horizontal line segments

in Fig.2.9(c) are of the same length, but one appears shorter than the other. Finally, all lines in Fig.2.9(d)that are oriented at 45°are equidistant and parallel. Yet the crosshatching creates the illusion that those lines are far from being parallel. Optical illusions are a characteristic of the human visual system that is not fully understood.21 

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Electromagnetic Spectrum

• The Electromagnetic Spectrum

– we perceive only a small range of colours of the

electromagnetic spectrum (~ 430nm –790nm)

o gamma rays, X rays, ultraviolet light, visible spectrum,

infrared, microwaves, radio waves, ...

22

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

– Fundamental equations

o Relation between wavelength (λ) and frequency (ν): λ = ���� o relation between energy(E) and frequency (ν): �� = ℎ��

23 

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• The Electromagnetic Spectrum

– we perceive only a small range of colours of the

electromagnetic spectrum (~ 430nm –790nm)

– objects are perceived by the light they reflect

oachromatic light: all wavelengths are reflected equally

ochromatic light: some wavelengths are reflected predominantly 24

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Light and EM Spectrum

*c* = λν *E h h* = ν, : Planck's constant.

***λ = wavelength, v = frequency, c = speed of light = 3 x 108 m/sec, E = energy*** 25 

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Light and EM Spectrum

► The colors that humans perceive in an object are determined by the nature of the light reflected from the object. 

e.g. green objects reflect light with wavelengths primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelength

26

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Light and EM Spectrum

► Monochromatic light: void of color

**Intensity** is the only attribute, from black to white

Monochromatic images are referred to as **gray-scale** images

► Chromatic light bands: 0.43 to 0.79 um

The quality of a chromatic light source:

**Radiance**: total amount of energy

**Luminance (lm)**: the amount of energy an observer perceives from a light source

**Brightness**: a subjective descriptor of light perception that is impossible to measure. It embodies the achromatic notion of intensity and one of the key factors in describing color sensation.

27

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Some Typical Ranges of illumination

• **Illumination**

**Lumen** — A unit of light flow or luminous flux

**Lumen per square meter (lm/m2)** — The metric unit of measure for illuminance of a surface

– On a clear day, the sun may produce in excess of 90,000 lm/m2 of illumination on the surface of the Earth

– On a cloudy day, the sun may produce less than 10,000 lm/m2 of illumination on the surface of the Earth

– On a clear evening, the moon yields about 0.1 lm/m2 of illumination

– The typical illumination level in a commercial office is about 1000 lm/m2

28

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Classification of Signals

29

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Classification of Signals

• **Analog Signals** (Continuous-Time Signals): Signals that are continuous in both the dependant and independent variable (e.g., amplitude and time). Most environmental signals are continuous time signals.

• **Discrete Sequences** (Discrete-Time Signals): Signals that are continuous in the dependant variable (e.g., amplitude) but discrete in the independent variable (e.g., time). They are typically associated with sampling of continuous-time signals.

• **Digital Signals**: Signals that are discrete in both the dependant and independent variable (e.g., amplitude and time) are digital signals. These are created by quantizing and sampling continuous-time signals or as data signals (e.g., stock market price fluctuations).

30

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

31

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

32 Faculty of Engineering & Technology 

Graphical Representation © Ramaiah University of Applied Sciences

Sampling

Quantizing

&

encoding

0001

Faculty of Engineering & Technology

Continuous-time analog signal 

Discrete-time analog signal 

Discrete-time digital signal 

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |

33

© Ramaiah University of Applied Sciences

Sampling

• Sampling period (sampling interval) – the time in seconds between samples

• Sampling frequency (sampling rate) – the number of samples per second, measured in Hertz (Hz)

���� =1����

where ���� denote the sampling frequency, ���� denote the sampling period.����2> �������� → ���� > 2��������

• **Theorem:** If the highest frequency(��������) contained in an analog signal ���� �� is �������� = �� and the signal is sampled at a rate ���� > 2�������� = 2�� then ���� �� can be exactly recovered from its sample values.34

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Sampling

35

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Sampling

• Digitization of the spatial coordinates, sample (x, y) at discrete values of (0, 0), (0, 1), ….

• f(x, y) is 2-D array

*f f f M*

(0,0) (0,1) (0, 1)



−

*f x y* ( , )



⎢⎢⎢⎢⎣⎡− − − −

⎥⎥⎥⎥⎦⎤

*f f f M*

(1,0) (1,1) (1, 1)

−

=

*f N f N f N M*

( 1,0) ( 1,1) ( 1, 1)

36

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Quantization

• Digitization of the light intensity function

• Each *f(i,j)* is called a pixel

• The magnitude of *f(i,j)* is represented digitally with a fixed number of bits - quantization

37

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Need for Digitization

• Why image digitization is necessary

• What is meant by signal bandwidth

• Select the sampling frequency of a given signal • Explain image reconstruction from sampled values

38

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Digital Image

39

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Image Digitization

• Why do we need Digitization • What is Digitization

• How to digitize an image

Faculty of Engineering & Technology

40

© Ramaiah University of Applied Sciences

Image Digitization

( ) ( ) ( )

*f x y I x y R x y* , , ,

=

*F(x,y) *

0 0

≤ ≤

*x L*

≤ ≤

*y H*

Point f(x,y) can also vary from 0 to infinity but practically its not possible hence its considered to vary from Imin to Imax

41 

Faculty of Engineering & Technology

min ( )max ,

*I f x y I*

≤ ≤

f(x,y) = point in the image

R(x,y) = reflectance at the point (x,y) and varies from 0-1 I(x,y) = intensity at the (x,y) and varies from 0- Infinity

© Ramaiah University of Applied Sciences

Image Digitization – Sampling & Quantization

• The most basic requirement for computer processing of images is availability of image in digital form.

• Digitization of an image is done by sampling and quantization. • The digitized image can then be processed by computer.

• To display, the processed digital image is converted back to analog form using DAC.

• The common method of image sampling is to scan the image row by row and sample each row.

42

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Theory of Real numbers

• Between any 2 points, there are infinite no. of points • An image should be represented by infinite no. of points • Each such image may contain one of the infinitely many possible intensity/ colour values needing infinite no. of bits

• Practically not possible in any Digital computer

• Naturally a way out is to be found….!!

• Take discrete values – Sampling and Quanitzation • Image is represented in a matrix (M x N) form as , where each element assumes a finite value

(1,0)........................... . (1, 1)

*f f f f N*

(0,0) (0,1) (0,2)......... (0, 1)

−

⎢⎢⎢⎢⎢⎢⎢⎢⎢⎣⎡− − − ⎥⎥⎥⎥⎥⎥⎥⎥⎥⎦⎤ 

Each point represents intensity

*f x y* ( , )

*f f N* −

=

at a point

We have to consider finite values for digitization

43

Faculty of Engineering & Technology

*f M f M N*

( 1,0).................... ( 1, 1)

© Ramaiah University of Applied Sciences

Sampling and Quantization

Image is represented by a matrix and 

each element is an integer value

Representation of an image as a Matrix is called Sampling

Each Matrix element represented by a finite values is called Quantization44

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Image Digitization – Sampling & Quantization

The figure explains the digitization of an image and

reconverting back to analog form:

45

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Sampling

Local Maxima

Local Minima

Delta dirac Function

x(t)

x(t) 

(t) (t)

δ(t)

(sampling function)

(t)

∞

Δ = ∑∂ − Δ

x(t)

x(t)

*comb t t t m t* ( , ) ( )

Δt

∂ = ( )

⎩⎨⎧ =

1; 0 *t*

*m*

=−∞

reconstructionx(t)

(t)

Δt/2

(t)

*t*

0;

*all other valuesof t*

*Xs t X t comb t t* 

( ) ( ). ( , )

= Δ

∑∞

= Δ ∂ − Δ

*X m t t m t*

( ) ( )

*m*

=−∞

(t)

46 

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Mathematics Behind Sampling

( ( ) ) ( ) ( )( ) ,

*Given discrete signal x n Signalin frequencydomainis givenby*⎜⎝⎛ Π

*N*

−

1

−

*j*

2

⎟⎠⎞

*nk*

∑

*F x n X k x n e* = =

*N*

*n*

=

0

*N*

−

1

*j*

⎜⎝⎛ Π 2

⎟⎠⎞

*nk*

∑

*x n X k e* ( ) ( ) =

*N*

*k *

=

0

47

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

*We knowthat*

*Xs t X t comb t t* ( ) ( ). ( , ) = Δ

Convolution

*Time Convolution is given as*

domain

∞

∫

*x t h t h T x t T dT*

( )\* ( ) ( ) ( )

= −

*given signals x t and h t*

2 ( ) ( ) *Convolution is given as*

*Fourier*

−∞

domain convolution is given as

∫∞

∞

⎢⎣⎡

∞

⎥⎦⎤

∫ ∫

−

*jwt*

F(h(t)\* x(t)) ( ) ( ) = −

*x t h t h T x t T dT*

( )\* ( ) ( ) ( )

= −

−∞

−∞

−∞

∞

∞

*h T x t T dT e dt*

∫ ∫

= −

− − − *jw t T jwT* ( )

h(t)

−∞ ∞

*h T x t T e dt e dT*

( )[ ( ) ]

−∞

x(-t)

=

∫

−

*jwT*

x(t) 

−∞

*h T X w e dT* ( ) ( )

∞

=

∫

−

*jwT*

Convolution in time domain in

multiplication in frequency domain

= 

Faculty of Engineering & Technology

*X w h T e dT*

( ) ( )

−∞

*X w H w*

( ) ( )

© Ramaiah University of Applied Sciences

48

Convolution – Concept

Convolution in time domain in 

multiplication in frequency domain

| **0** | **1** | **0** |
| --- | --- | --- |

**1 0 0 0 0 0 0 1**

h(n)

**2 3 2**

x(n) or x(-n)

**2 3 2 0 0 2 3 2 0 0 2 3 2** ∑∞

*y*(*n*) *h*(*m*)*x*(*n m*)

= −

*m*

=−∞

49 

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

50

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

51

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

52

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Convolution – Concept

X(w) 

Bandlimited

X(w) =0 ; |w|>w0

(w (w) 0)

H(w)

Y(w)

fs >2wo

53

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Aliasing and Anti-aliasing

fs < 2wo 

If sampling rate is not large enough (not larger than 2B Hz),

then interference among adjacent bands will occur, and this

results in the phenomenon of aliasing.

54

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

wx 

wy

2D Sampling

Bandlimited

F(wx,wy) >0 ;

|wx|>w0

|wy|>w0

*F s x y F x y comb x y x y*

( , ) ( , ) . ( , ; , )

= Δ Δ

∑ ∑∞

= Δ Δ ∂ − Δ − Δ *f m x n y t m x y n y*

**Δx Δy

Faculty of Engineering & Technology

*m n* ,

=−∞

( , ) ( , )

55

© Ramaiah University of Applied Sciences

Image Sampling

56

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Digital Quantization

t

u

p

t

u

o

r

o

l

o

c

e

t

e

r

c

s

i

d

57 

Faculty of Engineering & Technology

continuous colors 

mapped to a finite,

discrete set of colors.

continuous color input

© Ramaiah University of Applied Sciences

Sampling and Quantization

pixel grid

real image sampled quantized sampled & quantized

58

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Transform

illumination

energy into

digital images

Faculty of Engineering & Technology

Image Sensor

Sensors transform the incoming energy

into voltage and the output of the sensor

is digitized.

59

© Ramaiah University of Applied Sciences

Image Acquisition Using a Single Sensor60

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Image Acquisition Using Sensor Strips

Using Sensor Strips and Rings

61

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

62 Faculty of Engineering & Technology 

Image Acquisition

© Ramaiah University of Applied Sciences

Image Acquisition

• Images are typically generated by *illuminating* a *scene* and absorbing the energy reflected by the objects in that scene

• Typical notions of 

illumination and

scene can be way off:

– X-rays of a skeleton

– Ultrasound of an

unborn baby

– Electro

microscopic

images of

molecules

63

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

A simple image formation model

• Image as two-dimensional(2D) light-intensity function – ��(��, ��) = ��(��, ��) ��(��, ��) 

▪ the amount of source illumination incident on the scene being viewed

▪ the amount of illumination reflected by the objects in the scene.

– *i*(*x,y*) – illumination component at point (x, y)

– *r*(*x,y*) – reflectance component at point (x, y)

– *f(x,y)-* intensity at point *(x, y)*

where and

64

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Image Formation and Image Sampling

• Image Formation Model

– illumination i(x,y) from a source

– reflectivity r(x,y) = reflection / absorption in the scene f(x,y) = i(x,y) r(x,y)

• Image Sampling

– digital image can be seen as a 2D function f(x,y)

• x and y are the spatial coordinates

• f(x,y) is the grey level or intensity at position (x,y)

– a digital image must be sampled (digitized)

• in space (x,y): image sampling

• in amplitude f(x,y): grey-level quantization

65

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

A simple image model

• ***l*(*x,y*) - illumination range**

– 0.1 lm/m2(full moon) 

– 1000 lm/m2(office)

– 10'000 lm/m2(cloudy day)

– 90'000 lm/m2(sunny day)

• ***r*(*x,y*) – typical reflectance indixes** – black velvet (0.01)

– stainless steel (0.65)

– white paint (0.80)

– silver plate (0.90)

– snow (0.93)

log (cd/m2)

66

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Image Sampling and Quantization

• A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels

• Quantization is the process of converting a continuous **analogue** signal into a digital representation of this signal

• Remember that a digital image is always only an **approximation**of a real world scene

67

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Image Sampling and Quantization • conversion of continuous input signal to a digital form

continuous signal digitized image68

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• conversion of continuous input signal to a digital form69

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• conversion of continuous input signal to a digital form • sample f(x,y) in both coordinates(sampling)

70

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• conversion of continuous input signal to a digital form

• sample f(x,y) in both coordinates(sampling)

Digitizing the

coordinate

values

71

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• conversion of continuous input signal to a digital form

• sample f(x,y) in both coordinates(sampling)

• sample f(x,y) in amplitude(quantization)

Digitizing the

coordinate

values

72

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Cont..

• conversion of continuous input signal to a digital form

• sample f(x,y) in both coordinates(sampling)

• sample f(x,y) in amplitude(quantization)

Digitizing the

coordinate

values Digitizing the amplitude

values 

73

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Representing Digital Images

• The representation of an M×N numerical array as

– f(x,y) as a matrix of real numbers

*f f f N*

(0,0) (0,1) ... (0, 1)

⎡ ⎤ − ⎢ ⎥ *f f f N*

(1,0) (1,1) ... (1, 1)

*f x y*

= ⎢ ⎥

( , )... ... ... ... −

⎢ ⎥ ⎢ ⎥ ⎣ ⎦ − − − −

*f M f M f M N*

( 1,0) ( 1,1) ... ( 1, 1)

– elements of the matrix are called pixels (2D) 74

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Representing Digital Images

• Digital Images

– a finite set of digital values(picture elements = pixels) • each pixel is associated to a position in a 2D region

• each pixel has a value

can be thought of as a 

matrix (raster image / raster

map) of grey levels /

intensity values

digital image 

75

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Representing Digital Images

• Discrete intensity interval [0, L-1], L=2k

• The number b of bits required to store a M × N digitized image

b = M × N × k

76

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Sampling and Quantization

• How many samples to take?

– Number of pixels (samples) in the image

– Nyquist rate

• How many gray-levels to store?

– At a pixel position (sample), number of levels of color or intensity to be represented

77

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Sampling and Quantization

• How many samples to take?

– The Nyquist Rate

– Samples must be taken at a rate that is twice the frequency of the highest frequency component to be reconstructed.

– Under-sampling: sampling at a rate that is too coarse, i.e., is below the Nyquist rate.

– Aliasing: artefacts that result from under-sampling.78

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Spatial and Intensity Resolution

• Spatial resolution

— A measure of the smallest discernible detail in an image — stated with *line pairs per unit distance, dots (pixels) per unit distance, dots per inch (dpi)*

• Intensity resolution

— The smallest discernible change in intensity level

— stated with *8 bits, 12 bits, 16 bits, etc.*

**79

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences

Spatial and Intensity Resolution

• How many samples to take?



80

Faculty of Engineering & Technology

© Ramaiah University of Applied Sciences