4.6 Color Image Processing

- motives of color image processing :

  1. color : powerful descriptor that simplifies object identification and extraction from a scene
  2. human eye : can discern thousands of color shades and intensities

- two major areas :

  1. full color processing
  - image : acquired with a full-color sensor (TV, or color screen)
  2. pseudo-color processing
  - one of assigning a shade of color to a particular monochrome intensity

4.6.1 Color Fundamentals

- only attribute of achromatic light : intensity or gray-level

- three basic components of chromatic light : radiance, luminance, brightness · ·

  - radiance (Watts. W) ;
    - ✓ the total amount of energy that flow from the light source

  - luminance (Lumens. lm) ;
    - ✓ a measure of the amount of energy an observer perceives from a light source

    ex.) light emitted from a source operating in the infrared region
    - · significant energy → large radiance
    - · observer would hardly perceive it → almost zero luminance

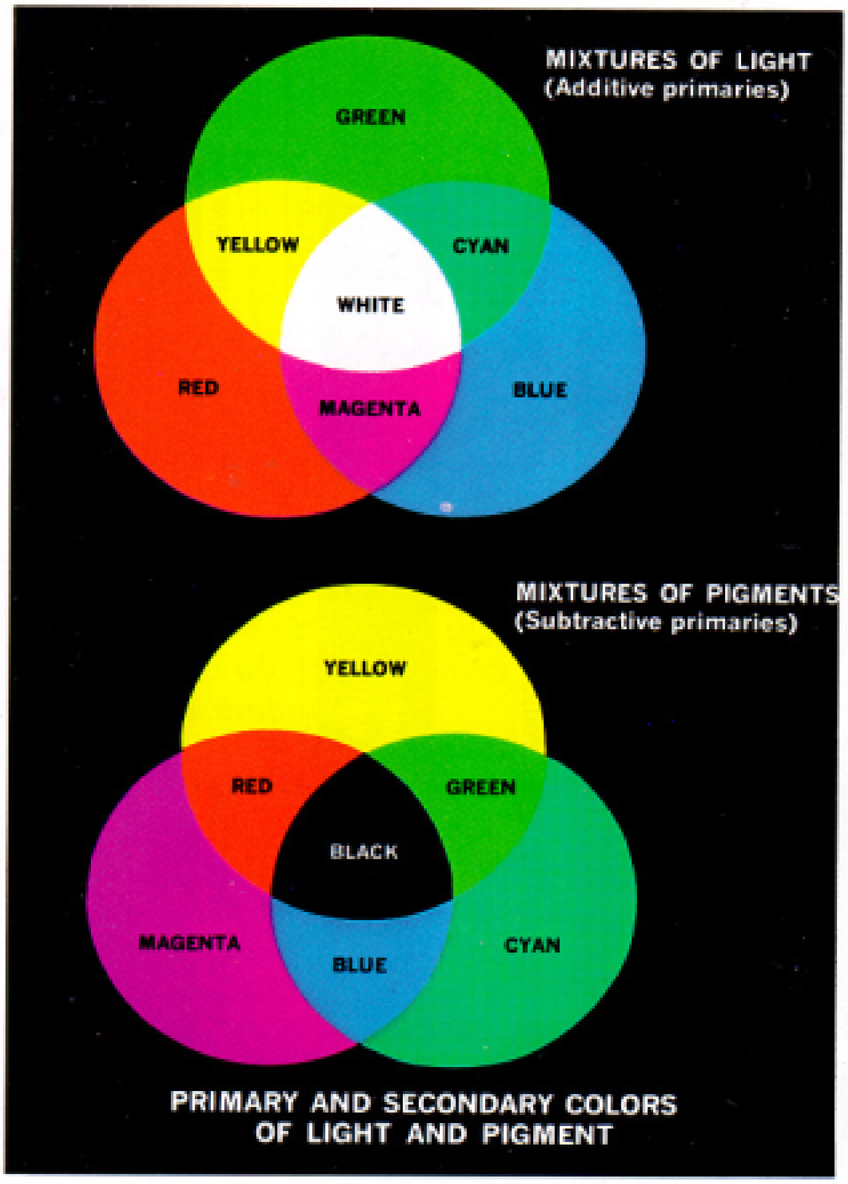
  - brightness;
    - ✓ subjective descriptor that is practically impossible to measure

- primary colors : R, G, B

  - all color : variable combination of R, G, B
  - CIE (the International Commission on Illumination)
    standard : wavelength values to three primary color
    B : 435.8 nm
    G : 546.1 nm
    R : 700 nm

- secondary color : plate Ⅲ (a)

  - magenta : R+B
  - cyan : G+B
  - yellow : R+G
  - white : R+G+B



- primary colors of pigments plate Ⅲ (b) :
  - magenta, cyan, yellow
  - secondary color : R, G, B

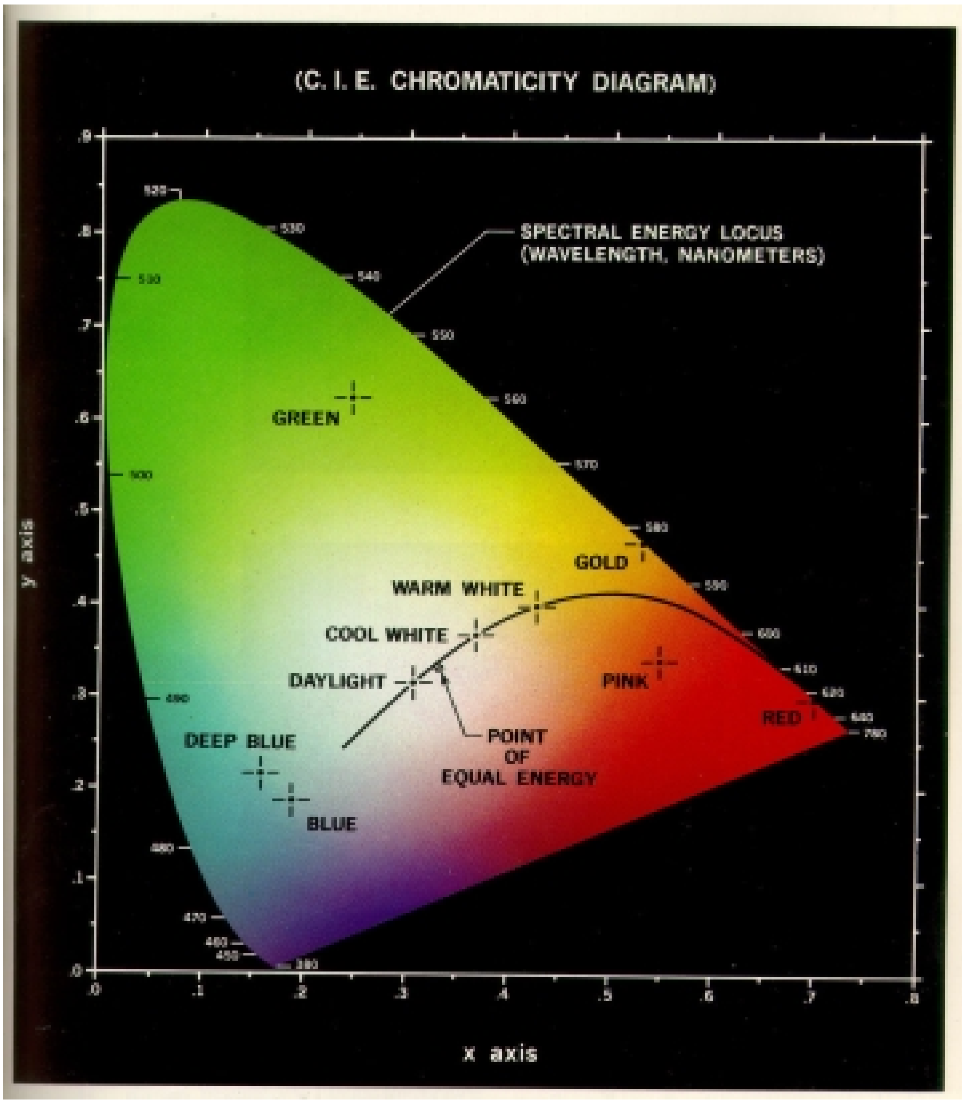
- characteristics used to distinguish one color from another : brightness, hue, saturation :
  - brightness
    : the chromatic notation of intensity
  - hue
    : dominant color (wavelength) as perceived by observer
  - saturation
    - ✓ relative purity or the amount of white light mixed with a hue
    - ✓ pure spectrum color : fully saturated
    - ✓ degree of saturation : inversely proportional to the amount of white light added

- tristimulus values : X, Y, Z :
  - the amounts of R, G, B needed to form any particular color

- trichromatic coeffs. :
  - $x = \frac{X}{X + Y + Z}$
  - $y = \frac{Y}{X + Y + Z}$
  - $z = \frac{Z}{X + Y + Z}$

    $x + y + z = 1$

- Chromaticity diagram : plate Ⅳ



- color components : a function of x (red like) and y (green like)
- z : obtained from eg. $z = 1-(x+y)$

ex.) green point in CIE chromaticity diagram : G : 62%, R : 25% → B : 13%

- Boundary of chromaticity diagram :
  - pure spectrum color : from violet (380 nm) to red (780 nm)
  - any point within boundary
    - ✓ some mixture of spectrum color

- the point of equal energy
  - ✓ equal fraction of the three primary colors
    - → CIE standard for white light

- saturation :

  - boundary of chromaticity diagram
    : pure saturation
  - within boundary of chromaticity diagram
    : less saturated
  - point of equal energy
    : zero saturation

4.6.2 Color Model

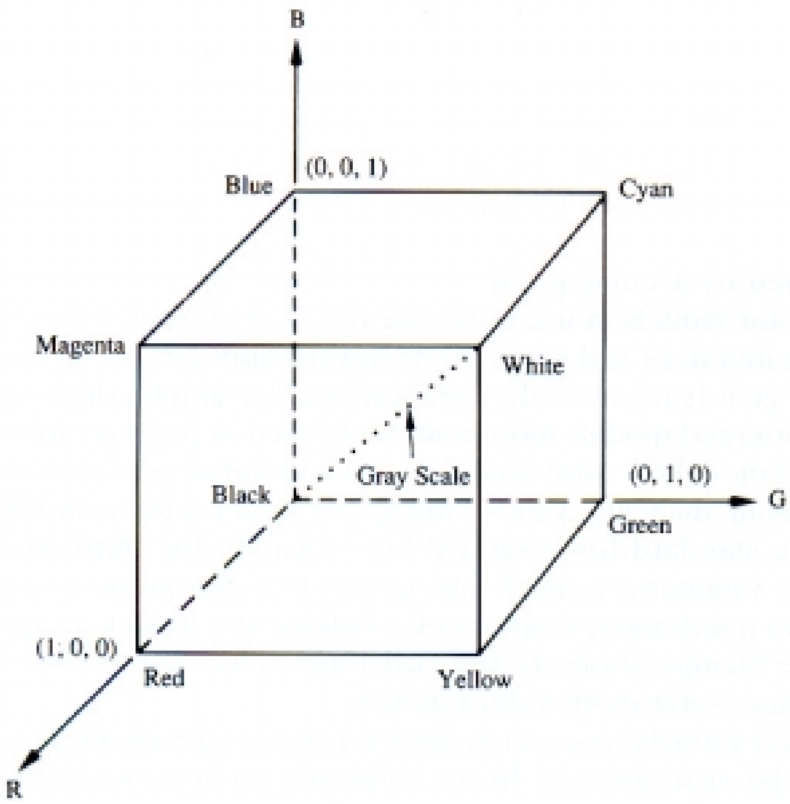
- H/W oriented models :
  - RGB model : color monitor, color video camera
  - CMY (cyan, magenta, yellow) model : color printer
  - YIQ model : color TV broadcast
    Where Y : luminance (명시도, 조명, 밝기)
    I,Q : two chromatic components (inphase, quadrature)

- Color image manipulation oriented model :
  - HSI (hue, saturation, intensity) model
  - HSV (hue, saturation, value) model

- Models often used in image processing :
  - RGB, YIQ, HIS

1) RGB model ; not very useful for IP since RGB components cannot be treated independently.

- Cartesian coordinate :



  - RGB, CMY, B/W, gray level (along the line joining B and W)
  - Normalized → R : [0,1]

- Example of usefulness of RGB model :
  - processing of aerial and satellite multispectral image data

- In color image enhancement :
  - histogram equalization of R, G, B respectively
    - ✓ three image intensities : altered differently
    - ✓ important color properties (ex. Flesh tones) : not appear natural

    ⇒ RGB model : not proper for this application

2) CMY model

- Secondary color of light

- RGB to CMY conversion :

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} K \\ G \\ B \end{bmatrix}$$

  - assumption : all color normalized

- Used in connection with generating hardcopy output (color printers and copiers)

3) YIQ model

- Used in commercial color TV broadcasting

- Recording of RGB for transmission efficiency and for maintaining compatibility with monochrome TV standard

- Y component : provide all information for monochrome TV

- RGB to YIQ conversion :

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Human eye : greater sensitivity to changes to illuminance than in hue of saturation :
  → Y : require more bandwidth (more bit rates)
  I, Q : less bandwidth (bit rates)

- Principal advantage of YIQ model :

Decoupling of luminance (Y) and color information (I,Q)

→ processing luminance without affecting its color component

- Histogram equalization :
  - only applied to Y components

4) HIS model

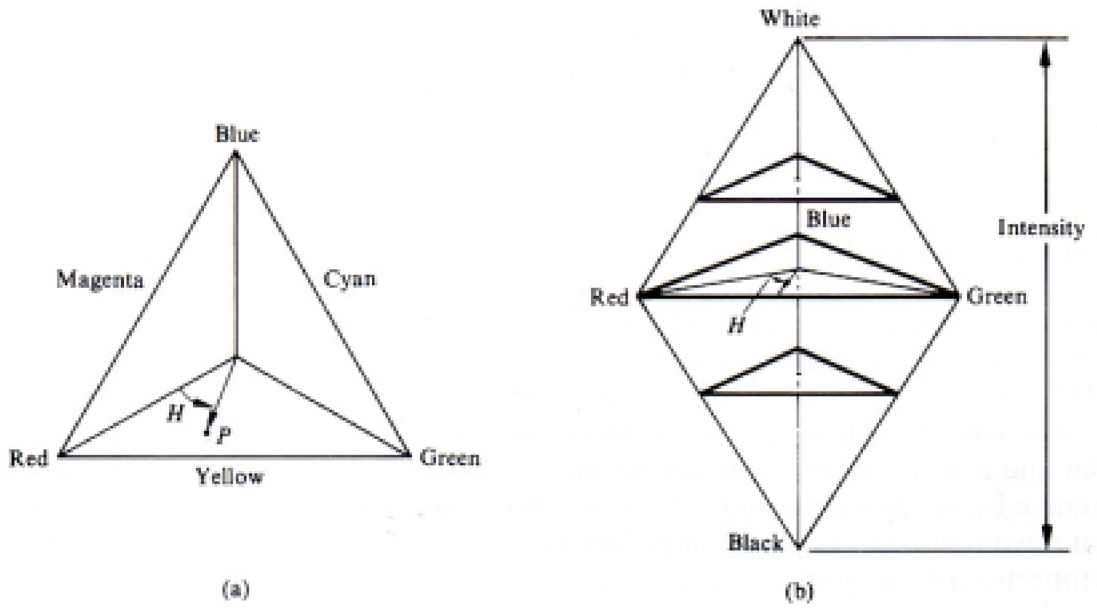
- two principal facts :
  - intensity I : decoupled from color inform.
  - S, H : intimately related to way that human perceives color

    ⇒ HIS : ideal tool for developing image processing algorithm

- usefulness of HIS :
  - design of imaging systems for automatically determining the ripeness of fruites
  - system for matching color samples

5) Conversion from RGB to HIS

- Color triangle :



- on the point P ;
  - ✓ H : angle of vector with respect to red

    Ex.) $H = 0^{o} \rightarrow red$

    $H = 60^{o} \rightarrow yellow$

    $H = 120^{o} \rightarrow blue$
  - ✓ S : proportional to distance from P to center
  - ✓ I : measured with respect to a line perpendicular to triangle and passing through its center

    $\Rightarrow$ (b)
- surface : purely saturated color

- Normalized RGB :

$$r = \frac{R}{R+G+B}, \quad g = \frac{G}{R+G+B}, \quad b = \frac{B}{R+G+B}, \quad r+g+b=1$$

- For R, G, B : each in [0,1] :

$$I = \frac{1}{3}(R + G + B)$$

$$S = 1 - \frac{3}{(R + G + B)}[\min(R, G, B)]$$

$$H = \cos^{-1}\left\{\frac{\frac{1}{2}[(R - G) + (R - B)]}{[(R - G)^2 + (R - B)(G - B)]^{1/2}}\right\}$$

4.6.3 Pseudo-color Image Processing

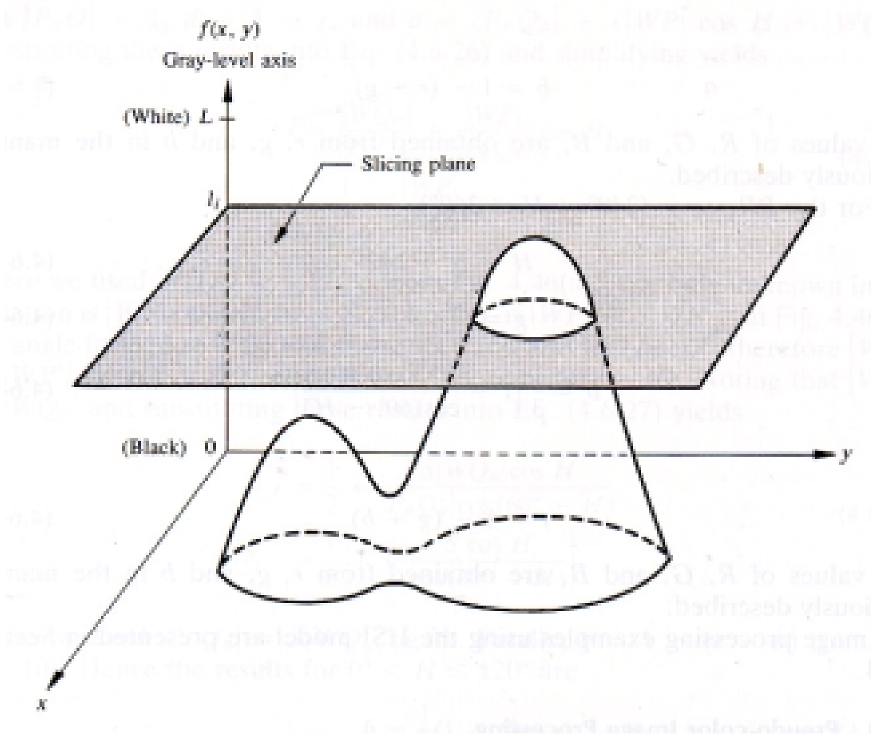
- Assigning color to monochrome image based on various properties of their gray-level content

1) Intensity slicing

- Placing planes parallel to the coordinate plane of the image

- Each plane : 'slices' the function in the area of intersection

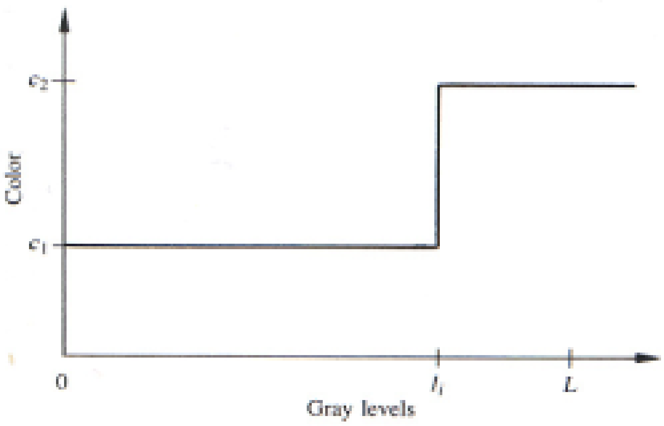
  $f(x, y) = l_i$



- Gray level above the plane : coded with one color
  Gray level below the plane : coded with the other color
  ⇒ two-color images

- In general :
  - M planes : $l_1, l_2, \ldots, l_M$, $0 < M < L$
    black $f(x, y) = l_0$
    white $f(x, y) = L$
  → partition the gray scale into M+1 regions

- Color assignment :
  $f(x, y) = C_k$, if $f(x, y) \in R_k$
  where C_k : color associated with the k-th region R_k



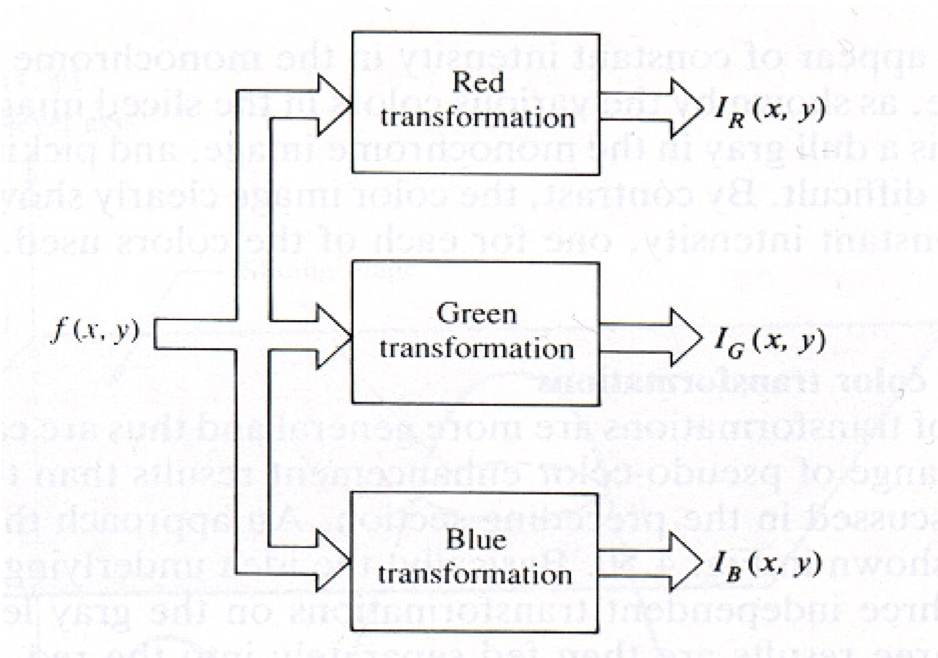
ex.) plateⅤ: Picker Thyroid Phantom(radiation test pattern)


(a)


(b)

- Regions that appear of constant intensity in monochrome image
  → quite variable in color image

2) Gray level to color transformations



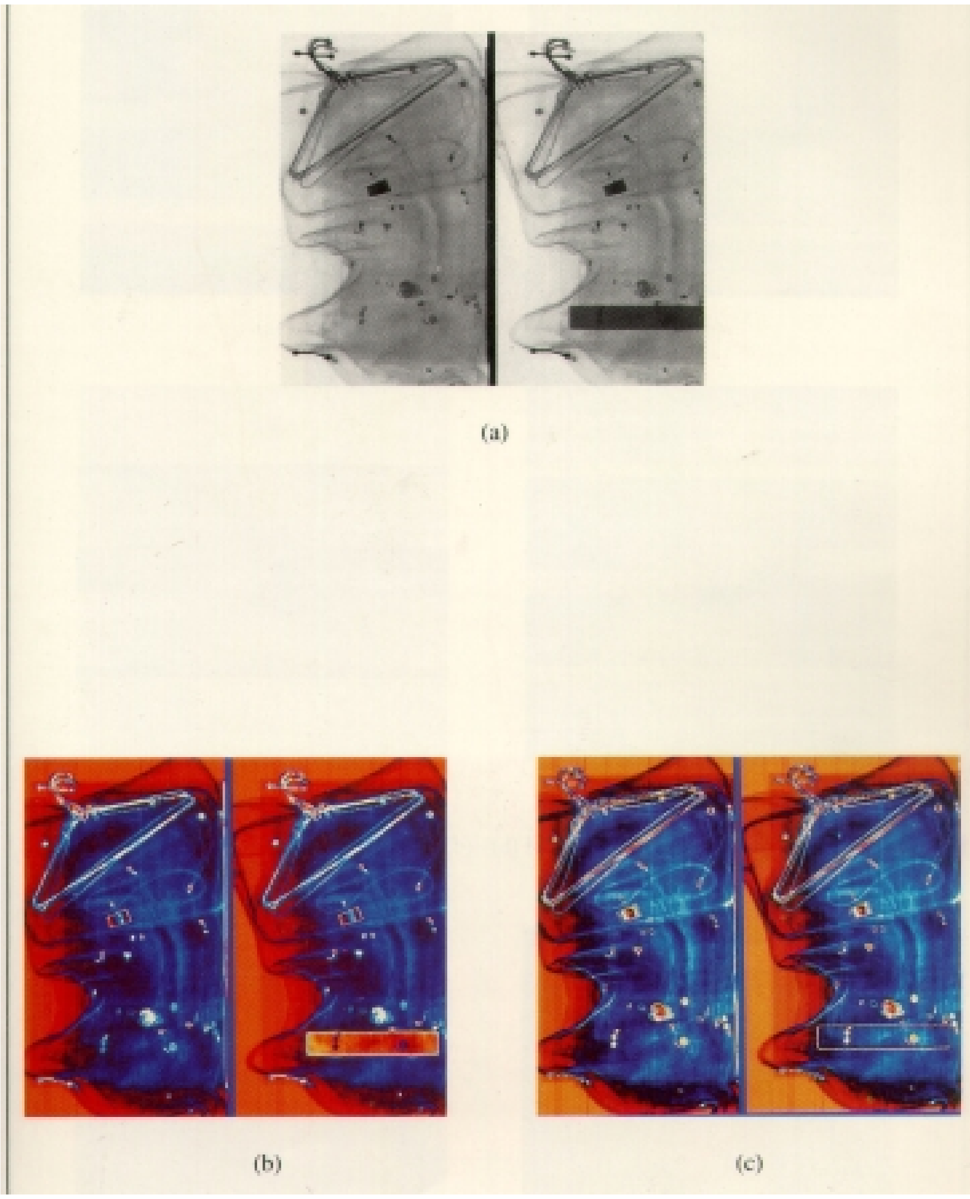
- Three independent transformation on the gray level of any input pixel → composite image

- Transformation on the gray-level values instead of function of position

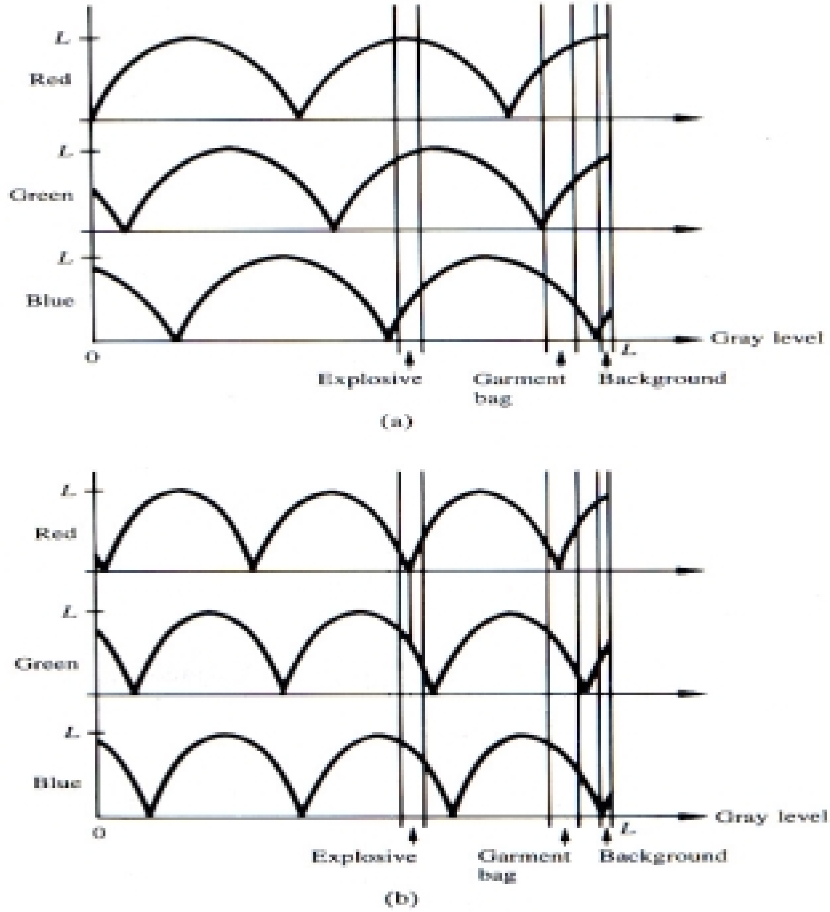
- Color content : modulated by nature of transformation function

- Transformation : smooth, nonlinear function
  → more flexibility than intensity slicing method

ex.) plate Ⅵ



- luggage (a) : ordinary article
  (b) : ordinary article + plastic explosives
  : transformation function used



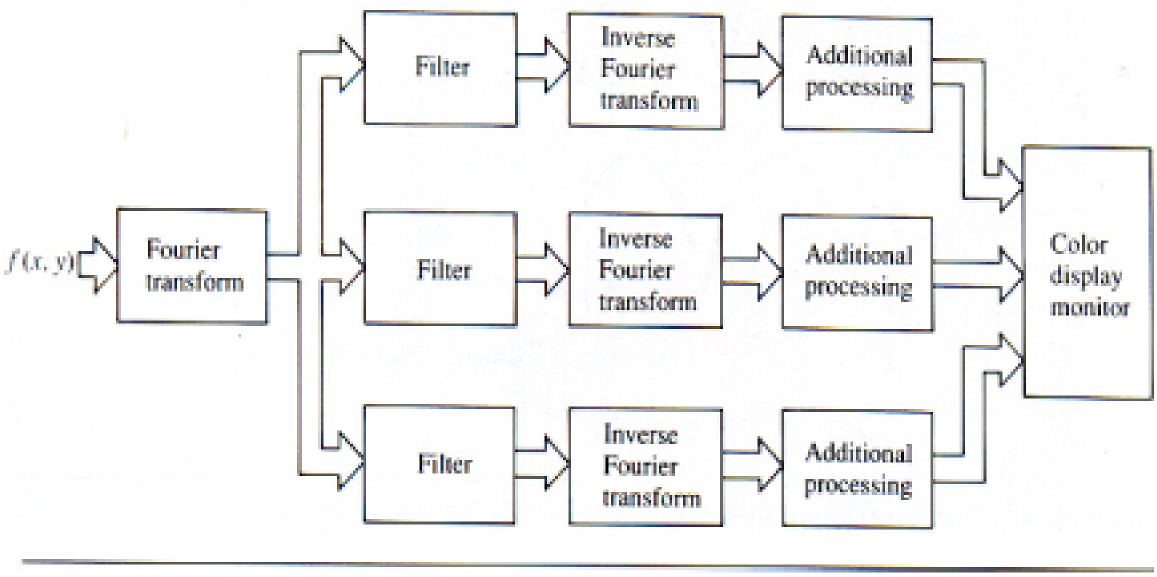
- sinusoidal function ;
  - ✓ relatively constant regions around peaks
  - ✓ regions that change rapidly near the valleys

- changing in phase and freq. ;
  - ✓ emphasize (in color) ranges in gray level
  - ✓ if three transformation. : the same phase and freq.
    - → monochrome image
  - ✓ if a small change in phase between three transformation.
    - → little change in pixel whose gray levels correspond to peaks in sinusoids, if especially the sinusoids : broad profile (low freq.)
  - ✓ pixels with gray level values in steep section of sinusoid
    - → assigned a much stronger color content because of a significant differences between amplitude of three transformation (sinusoids)

      (a) transformation → plate Ⅳ (b)

      (b) transformation → plate Ⅳ (c)

3) Filtering approach



- Signals through three filters :
  → fed into R, G, B inputs of color monitor

- Objective :
  - to color code regions of an image based on freq. Content

- Additional processing

- Typical filters : LPF, BPF (or BRF), HPF

- On ideal band reject filter (IBRF) :

$$H(u,v) = \begin{cases} 0 & if \quad D(u,v) \le D_0 \\ 1 & if \quad D(u,v) > D_0 \end{cases}$$

where $D(u,v) = \left[(u-u_0)^2 + (v-v_0)^2\right]^{1/2}$

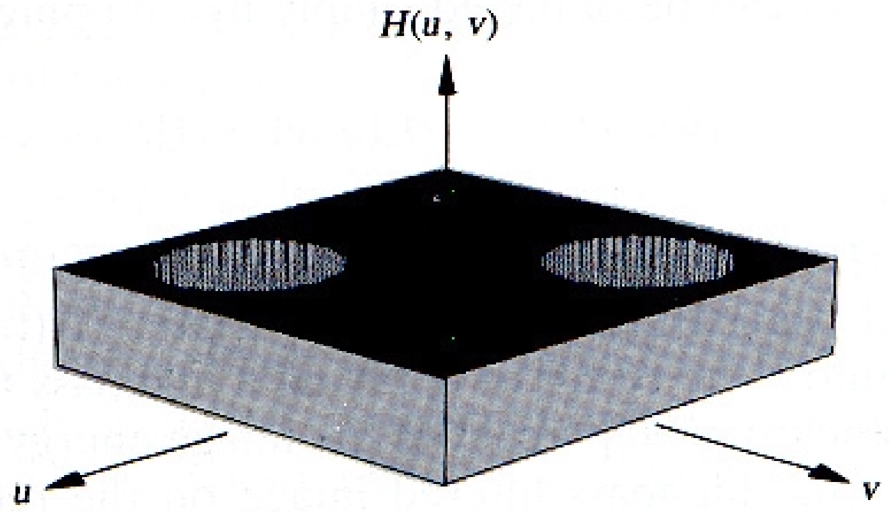
- IBRF that is not about the origin :

$$H(u,v) = \begin{cases} 0 & if \quad D_1(u,v) \le D_0 \quad or \quad D_2(u,v) \le D_0 \\ 1 & otherwise \end{cases}$$

where $D_1(u,v) = \left[(u-u_0)^2 + (v-v_0)^2\right]^{1/2}$

$D_2(u,v) = \left[(u-u_0)^2 + (v-v_0)^2\right]^{1/2}$

ex.)



- Radially symmetric IBRF :

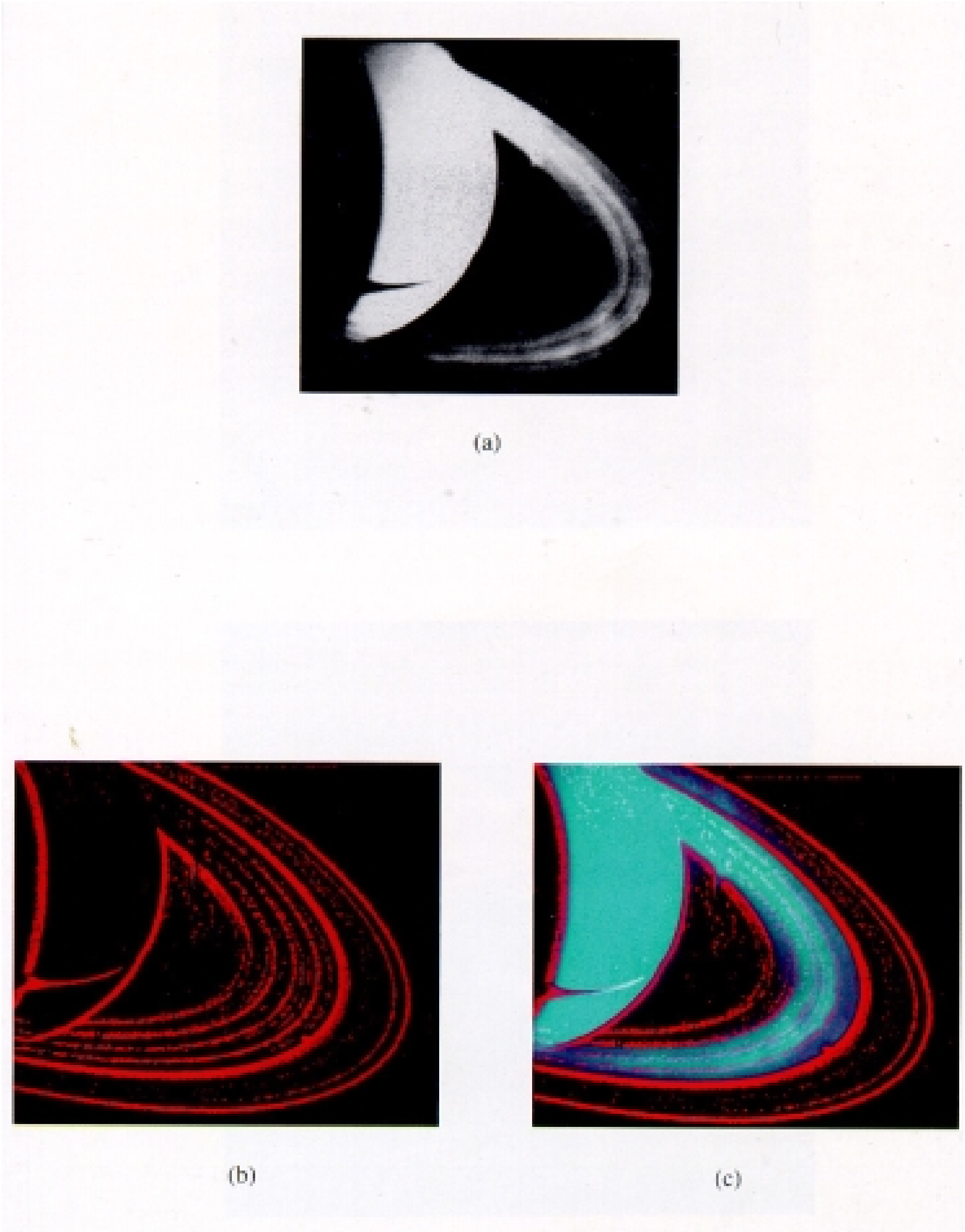
$$H(u,v) = \begin{cases} 1 & if \quad D(u,v) < D_0 - \frac{W}{2} \\ 0 & if \quad D_0 - \frac{W}{2} \le D(u,v) \le D_0 + \frac{W}{2} \\ 1 & if \quad D(u,v) > D_0 + \frac{W}{2} \end{cases}$$

where W : bandwidth
D_0 : radial center

n-th order Butterworth IBRF :

$$H(u,v) = \frac{1}{1 + \left[\dfrac{D(u,v)W}{D^2(u,v) - D_0^2}\right]^{2n}}$$

ex.) plate Ⅶ : Butterworth Filtering

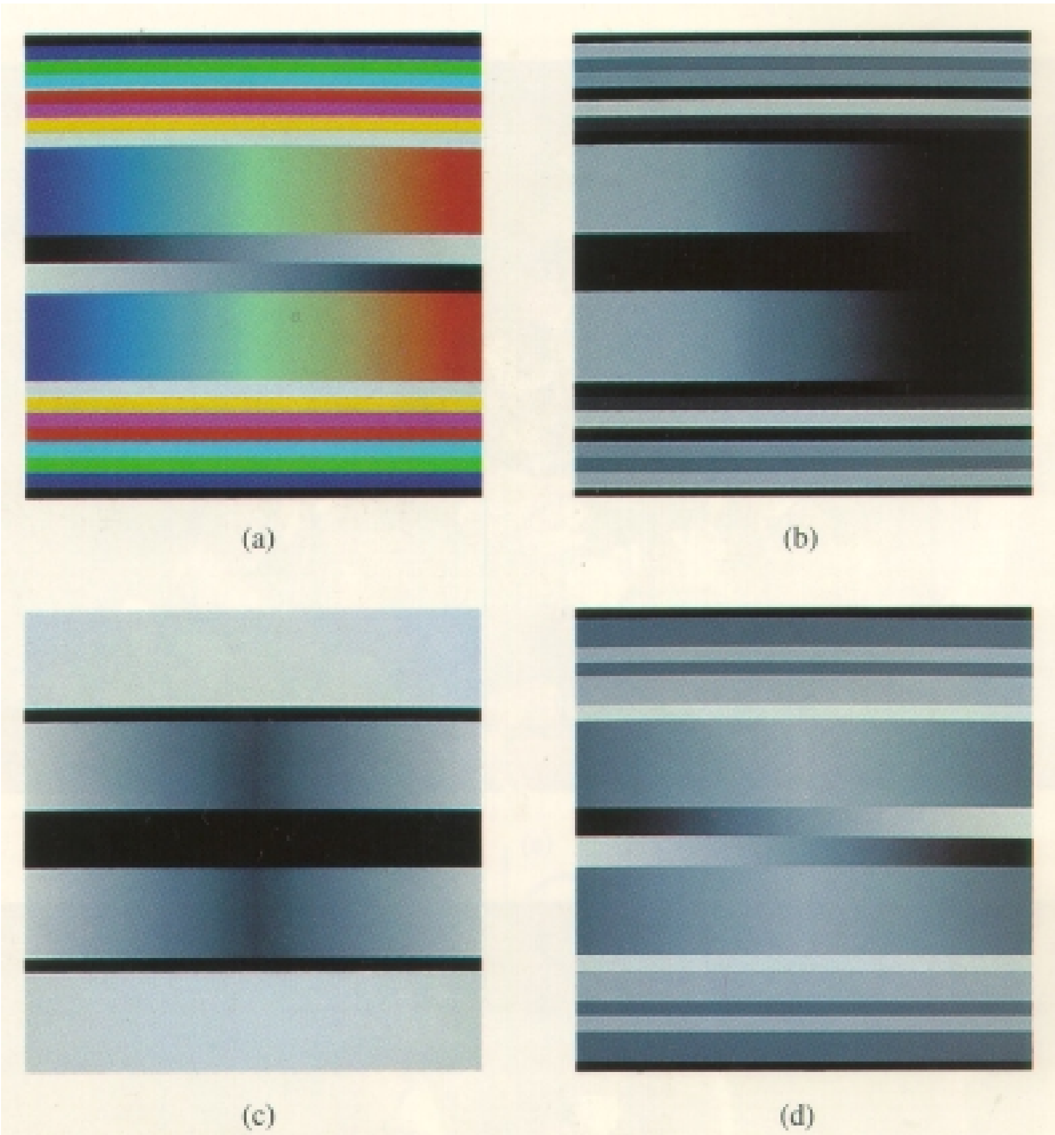


(a) (b) (c)

4.6.4 Full-color Image Processing (full color techniques for image enhancement)

1) HIS component images from on RGB image

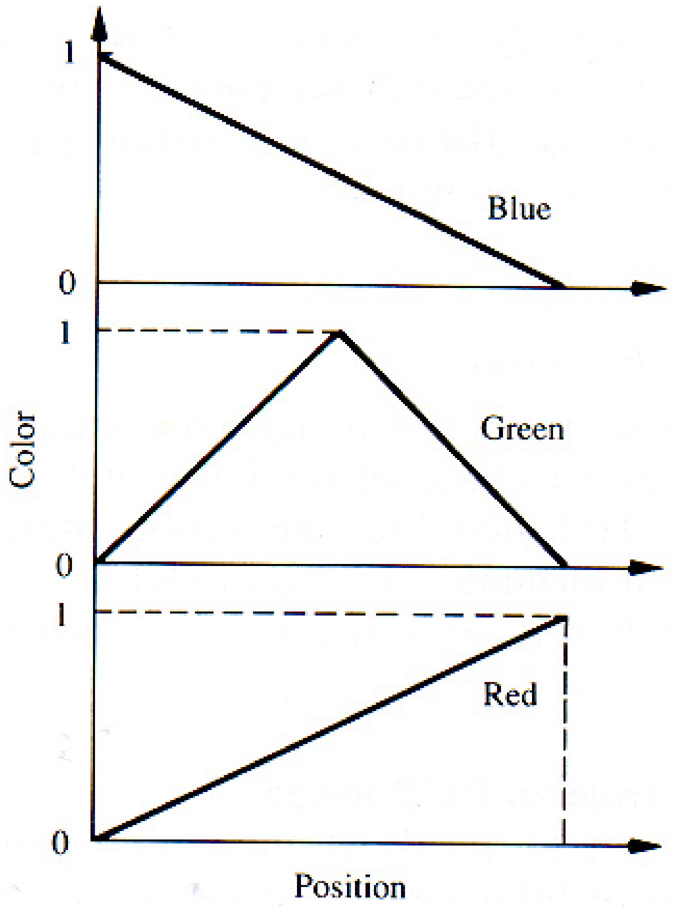
● Plate Ⅷ :



(a) : eight bands: black(1),pure primaries(3),secondaries(3),white(1)

- multi color band : R, G, B
- two gray-scale wedge in opposite direction

mixture of R, G, B



- 24-bit color image :

  - R, G, B : each 8-bit (0~255)

- HIS :

  - H : plate Ⅷ (b)

    values expressed in degree

    red : the darkest gray

    monochrome : no hue (displayed in block)

  - S : pure primaries : max value

    zero intensity → saturation : not defined

    monochrome : min value (zero)