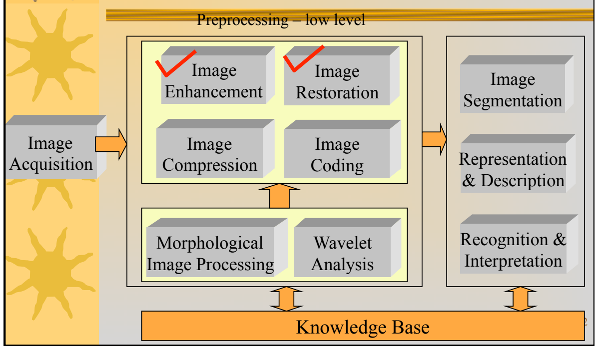
ECE 472/572 - Digital Image Processing

Lecture 10 - Color Image Processing

10/25/11

Roadmap



Questions

- Color interpretation
  - Color spectrum vs. electromagnetic spectrum
  - Why does CIE standard specify R, G, B as the primary colors? Are there actually single special band as R, G, or B?
  - Why does the Bayer color filter array have 50% green but 25% red and blue?
  - What is additive color system? What is subtractive color system?
  - What is hue and saturation? or what is chromaticity?
  - What is chromaticity diagram? tristimulus? Why can't the three primary colors generate all the visible colors specified in the diagram? Where is brown?
  - Comment on the different usages of RGB, CMYK, HSI, and L*a*b* color models. What is the color gamut of color monitors, color printing devices, and L*a*b*?
  - What is "safe color"?
- Color processing
  - What is the difference between tonal and color correction?
  - What is the difference between processing using RGB model vs. HSI model?

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Color spectrum

- When passing through a prism, a beam of sunlight is decomposed into a spectrum of colors: violet, blue, green, yellow, orange, red
- 1666, Sir Isaac Newton

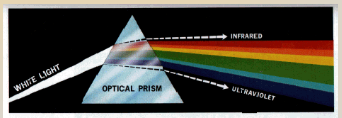

Plate I. Color spectrum seen by passing white light through a prism. (Courtesy of General Electric Co., Lamp Business Division.)

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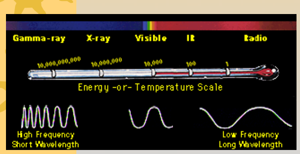
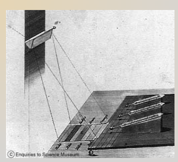
Electromagnetic energy spectrum

- Ultraviolet ←→ visible light ←→ infrared
- The longer the wavelength (meter), the lower the frequency (Hz), and the lower the energy (electron volts)
- The discovery of infrared (1800, Sir Frederick William Herschel)
- What is infrared? http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/





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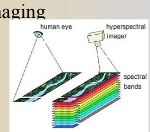
Hyperspectral imaging

- AVIRIS (Airborne Visible-Infrared Imaging Spectrometer)
  - Number of bands: 224
  - Wavelength range (μm): 0.4-2.5
  - Image size: 512 x 614



- Spectral range
  - visible light (0.4 ~ 0.77μm)
  - near infrared (0.77 ~ 1.5μm)
  - medium infrared (1.5 ~ 6μm)
  - far infrared (6 ~ 40μm)

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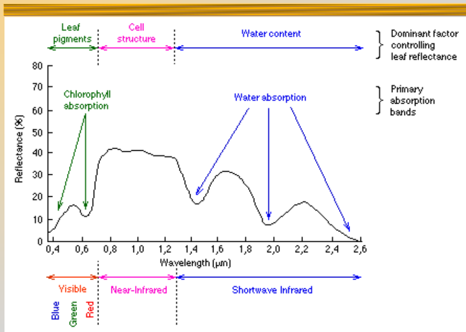
A typical spectral reflectance pattern of green vegetation



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Some questions

- What does it mean when we say an object is in a certain color?
- Why are the primary colors of human vision red, green, and blue?
- Is it true that different portions of red, green, and blue can produce all the visible color?
- What kind of color model is the most suitable one to describe human vision?

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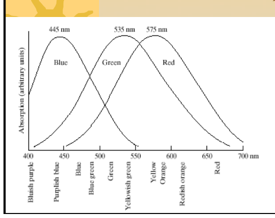
Primary colors of human vision

Detailed experimental curve available in 1965



- Cones are divided into three sensible categories
  - 65% of cones are sensitive to red light
  - 33% are sensitive to green light
  - 2% are sensitive to blue light
- For this reason, red, green, and blue are referred to as the primary colors of human vision. CIE standard designated three specific wavelength to these three colors in 1931.
  - Red (R) = 700 nm
  - Green (G) = 546.1 nm
  - Blue (B) = 435.8 nm

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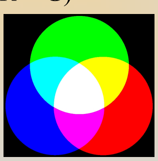
Some clarifications

- No single color may be called red, green, or blue.
- R, G, B are only specified by standard.

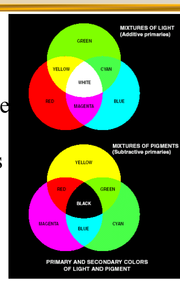
Secondary colors

- Magenta (R + B)
- Cyan (G + B)
- Yellow (R + G)



Primary colors of pigment

- A primary color of pigment refers to one that absorbs the primary color of the light, but reflects the other two.
- Primary color of pigments are magenta, cyan, and yellow
- Secondary color of pigments are then red, green, and blue



a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Additive vs. Subtractive color system

- involves light emitted directly from a source
- mixes various amounts of red, green and blue light to produce other colors.
- Combining one of these additive primary colors with another produces the additive secondary colors cyan, magenta, yellow.
- Combining all three primary colors produces white.

- Subtractive color starts with an object that reflects light and uses colorants to subtract portions of the white light illuminating an object to produce other colors.
- If an object reflects all the white light back to the viewer, it appears white.
- If an object absorbs (subtracts) all the light illuminating it, it appears black.

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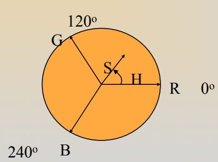
Color characterization

- Brightness: chromatic notion of intensity
- Hue: dominant color perceived by an observer
- Saturation: relative purity or the amount of white mixed with a hue



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Some clarifications

- So when we call an object red, orange, etc. we refer to its hue

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Chromaticity

- Chromaticity: hue + saturation
- Tristimulus: the amount of R, G, B needed to form any color (X, Y, Z)
- Trichromatic coefficients: x, y, z

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z}$$
$$x + y + z = 1$$

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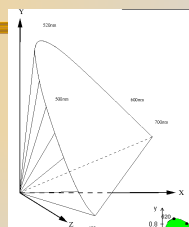
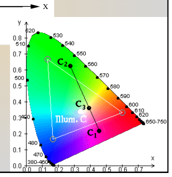
Chromaticity diagram

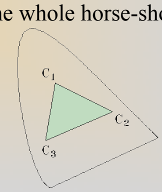
- CIE standard (1931)
- Shows all the visible colors
- Some questions:
  - Can different portions of R, G, B create all the visible colors?
  - Where is brown in the diagram?





Answers

- Chromaticity diagram only shows dominant wavelength (hue) and the saturation, and is independent of the amount of luminous energy (brightness)
- A triangle can never cover the whole horse-shoe shape diagram



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Color models

- RGB model
  - Color monitor, color video cameras
- CMY model
  - Color printers
- HSI model
  - Color image manipulation

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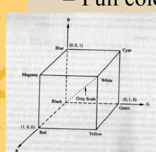
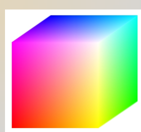
RGB model

- Color monitor, color video cameras (additive color system)
- Pixel depth – nr of bits used to represent each pixel
  - Full color image (24 bits)





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CMY model

- Color printers and copiers (subtractive color system)
  - CMYK color model
  - Four color printing
- Deposit colored pigment on paper

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

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HSI model

- The intensity component (I) is decoupled from the color components (H and S)
  - Ideal for developing image processing algorithms
- H and S are closely related to the way human visual system perceives colors

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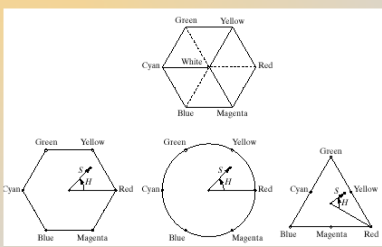
Hue and Saturation



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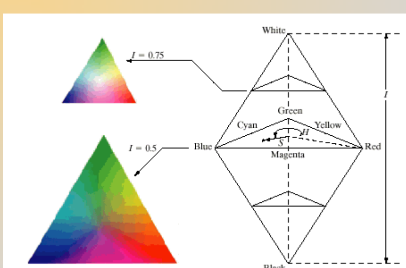
Hue, Saturation, Intensity



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RGB-to-HSI conversion (*)

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

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

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

$$H = \begin{cases} \theta & G \geq B \\ 2\pi - \theta & G \leq B \end{cases}$$

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HSI-to-RGB conversion (*)

- For 0º <= H < 120º

$$R = I\left[1 + \frac{S\cos(H)}{\cos(60^\circ - H)}\right], B = I(1-S), G = I - R - B$$

- For 120º <= H < 240º

$$G = I\left[1 + \frac{S\cos(H - 120^\circ)}{\cos(180^\circ - H)}\right], R = I(1-S), B = I - R - G$$

- For 240º <= H < 360º

$$B = I\left[1 + \frac{S\cos(H - 240^\circ)}{\cos(300^\circ - H)}\right], G = I(1-S), R = I - G - B$$

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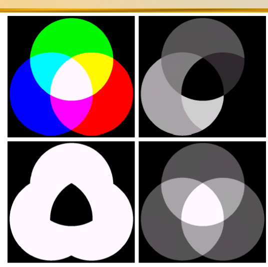
RGB vs. HSI



a b
c d

FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

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Summary

- Color spectrum vs. EM spectrum
  - Wavelength vs. frequency
  - Middle IR, near IR, far IR, visible
- Primary color vs. secondary color for human vision
  - Primary color of pigment
- Additive vs. subtractive color system
- Color characterization
  - Chromaticity
    - hue + saturation
    - Chromaticity diagram
  - Brightness
- Color models
  - RGB vs. CMYK vs. HSI

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Color image processing

- Pseudo-color image processing
  - Assign color to monochrome images
  - Intensity slicing
  - Gray level to color transformation
    - Spatial domain approach – three different transformation functions
    - Frequency domain approach – three different filters
- Full-color image processing
  - Color image enhancement and restoration
  - Color compensation

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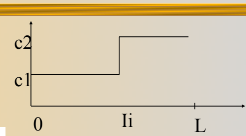
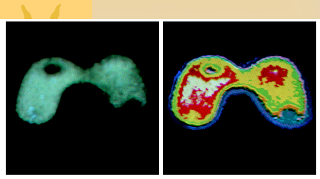
Intensity slicing

- Similar to thresholding





a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

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Gray level to color transformation – spatial domain

- Perform three independent transformations on the gray level of any input pixel.
- The three results can then serve as the red, green, and blue components of a color image

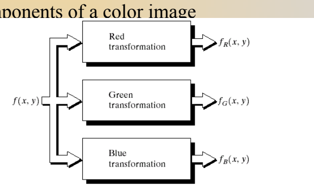

FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

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Examples

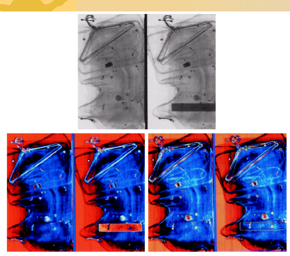


FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

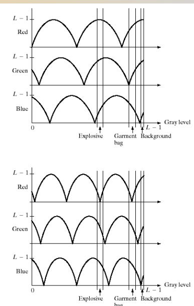


FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

Example 2

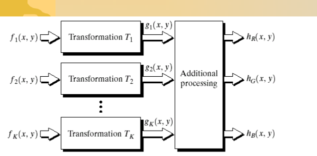
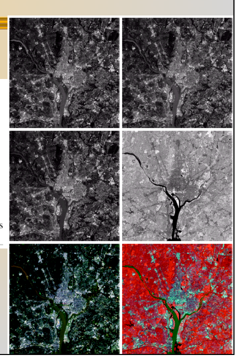
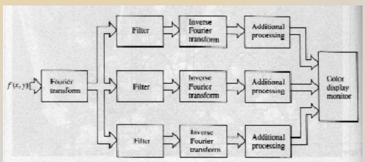


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.



Gray level to color transformation – frequency domain

- Color code regions of an image based on frequency content
- The Fourier transform of an image is modified independently by three filters to produce three images used as Fourier transform of the R, G, B components of a color image
- Additional processing can be any image enhancement algorithm like histogram equalization



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Example

- Red from highpass
- Green from bandpass
- Blue from lowpass

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Full-color image processing

- Color transformations
  - Processing in RGB, HSI, or CMY(K) space
- Tone and color corrections
  - Calibrate images using the CIELAB model (L*a*b* model)
- Point-based processing
- Mask-based processing

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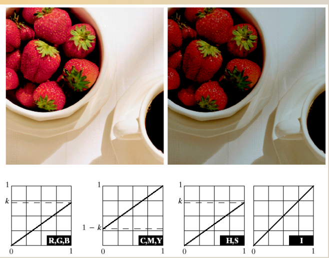
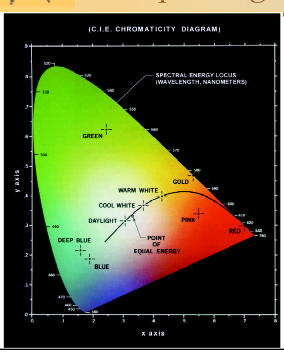
Adjusting intensity in different color spaces

a b
c d e

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)



Color gamut of color monitor and color printing



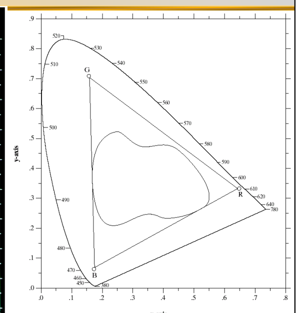


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

CIELAB (L*a*b* color model)

- Maintain a high degree of color consistency between the monitors used and the eventual output devices
- Device-independent color model that relates the color gamuts of the monitors and output devices

$$L^* = 116 \cdot h\left(\frac{Y}{Y_W}\right) - 16$$

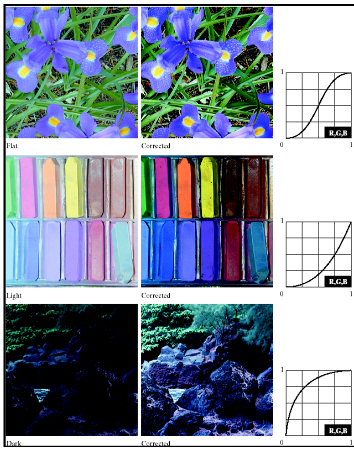
$$a^* = 500\left[h\left(\frac{X}{X_W}\right) - h\left(\frac{Y}{Y_W}\right)\right]$$

$$b^* = 200\left[h\left(\frac{Y}{Z_W}\right) - h\left(\frac{Z}{Z_W}\right)\right]$$

$$h(q) = \begin{cases} \sqrt[3]{q} & q > 0.008856 \\ 7.787q + 16/116 & q \le 0.008856 \end{cases}$$

The CIELAB gamut encompasses the entire visible spectrum and can represent accurately the colors of any display, print, or input device

Tonal correction example



Color is not changed (RGB or I)

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Color correction example

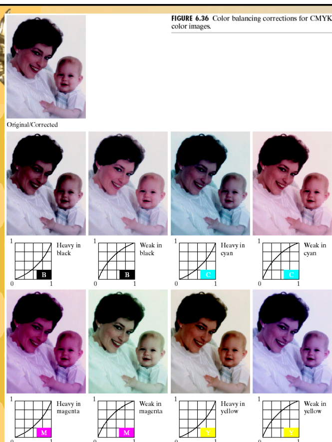

FIGURE 6.36 Color balancing corrections for CMYK color images.

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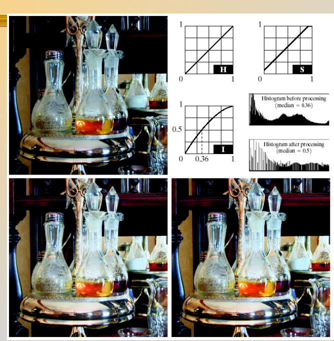
Histogram processing



a b
c d

FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

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Mask-based processing

- Per-image basis vs. direct operation on color vector space

$$f(x, y) = s$$

$$f(x, y) = \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

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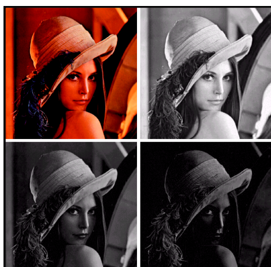
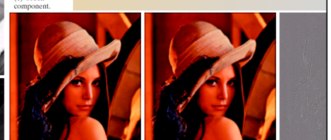


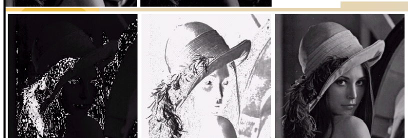
a b
c d

FIGURE 6.38 (a) RGB image. (b) Red component image. (c) Green component.



a b c

FIGURE 6.40 Image smoothing with a 5 × 5 averaging mask. (a) Result of processing image. (b) Result of processing the intensity component of the HSI image and conve ference between the two results.



a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

Color image smoothing

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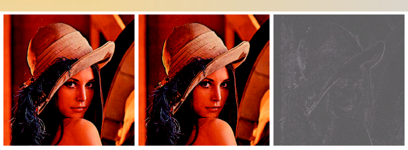
Color image sharpening



a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the intensity component and converting to RGB. (c) Difference between the two results.

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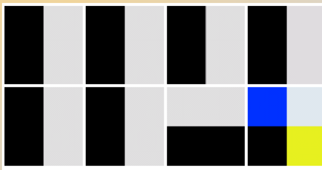
Color edge detection

- Section 6.7.3



a b c d
e f g h

FIGURE 6.45 (a)–(c) *R*, *G*, and *B* component images and (d) resulting RGB color image. (f)–(g) *R*, *G*, and *B* component images and (h) resulting RGB color image.

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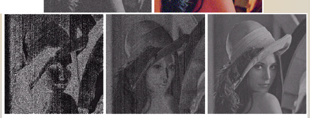
Noise in color image

a b
c d

FIGURE 6.48 (a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]



a b c

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.

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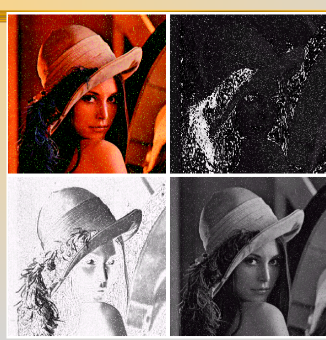

a b
c d

FIGURE 6.50 (a) RGB image with green plane corrupted by salt-and-pepper noise. (b) Hue component of HSI image. (c) Saturation component. (d) Intensity component.

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