CHAPTER 10

Colour Image Processing

When you take pictures of nature with passion, nature poses for you more passionately!

–Mehmet Murat ildan

LEARNING OBJECTIVES

Colour is one of the most important features of an object. Often, the colour of an object plays a crucial role in identifying it. This chapter provides an overview of colour image processing. After studying this chapter, the reader will become familiar with the following:

- Colour fundamentals
- Colour models
- Pseudocolour image processing
- True colour image processing

10.1 INTRODUCTION

Colour is necessary for two reasons. The first reason is to identify the object. Identification is often improved by colour information. The second major reason is to facilitate the manual analysis by highlighting the region of interest (ROI) in different colours. This improves the visualization of the image. Colours also improve the perception of an image dramatically. Figures 10.1(a) and 10.1(b) illustrate the perceptional quality difference between grey and colour images.

Colour image processing is divided into the following two major groups:

Full or true colour processing This subject deals with the acquisition, display, and printing of full-colour images. The colour range of full or true colour images are dependent on the hardware of the computer systems used. It is difficult to mention one application where colour images are not helpful. One possible domain where colour images are not used much is the medical domain where a majority of the images are grey scale images. Hence full colour processing is useful in all domains where full colour images are used.

(a) (b)

Fig. 10.1 Perception of an image (a) Grey image (b) Colour images (Refer to the OUPI website for the colour image)

Pseudocolour processing The purpose of pseudocolour processing is to assign artificial colours to a monochrome image. For example, colours can be added to a grey scale image based on the intensity values to facilitate image analysis.

10.2 COLOUR IMAGE STORAGE AND PROCESSING

In colour images, the pixel colours are obtained by mixing the primary colours—red, green, and blue. The range of the colours is very high for true colour images. Therefore, true colour images are used in imaging applications where a large number of colours is used. There are two ways of storing colour images.

In *component ordering*, a colour image is stored as three identical intensity images, F_G, F_R, and F_B. The values of the pixels of the image are obtained by accessing all the three identical intensity images together.

Mostly, true colour images use 24 bits to represent all the colours. Hence, colour images can be considered as three-band images or a stack of three matrices. The number of colours possible is 1,67,77,216 (256^3), that is, approximately 16.7 million colours.

Packed ordering is another method, where every pixel contains all the three colour components packed together. It can be mathematically represented as

$$F(x, y) = (R(x, y), G(x, y), B(x, y))$$

Figure 10.2 illustrates how the image is stored in packed ordering.

An indexed image is a special category of full colour image. Since the human eye cannot perceive a million different colours, the number of colours in a full colour image can be reduced. This is achieved by creating an additional colour map, colour gamut, or palette with the image. In this method, a pixel can be considered as an eight-bit pointer to the colour index of the colour map, which has RGB components. Using this indexed approach, the number of bits can be drastically reduced.

Scanned with OKEN Scanner

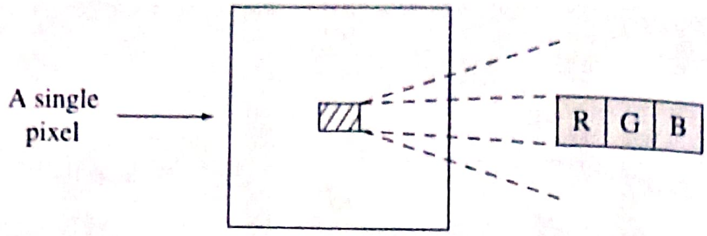


Fig. 10.2 Packed ordering

The advantage of the indexed method is that the size of the original image is less than the size of the true colour image as the indexed image uses only eight bits. However, the important fact to be noted is that the colour table should be saved as part of the image.

2.1 Conversion of Colour Image to Grey Scale Image

A colour image can be converted to a grey scale image by replacing the RGB values by the luminance value for each pixel. The luminance value can be obtained by

$$Y = \frac{R+G+B}{3}$$

This is a simpler technique, but the resultant image is too dark in the red areas and too bright in the blue areas. Therefore, a method that uses weights can be used as follows:

$$Y = w_R R + w_G G + w_B B$$

The typical values for the weights are $w_R = 0.2125$, $w_G = 0.7154$, and $w_B = 0.072$

(a) (b)

Fig. 10.3 Conversion of colour image to grey scale image (a) Colour image (b) Grey scale image (Refer to the OUPI website for the colour image)

A sample colour image and its grey scale image are shown in Figs 10.3(a) and 10.3(b) respectively. Similarly, desaturation is a process of removing the RGB in a linear manner. It can be expressed as follows:

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} Y \\ Y \\ Y \end{pmatrix} + k \begin{pmatrix} R-Y \\ G-Y \\ B-Y \end{pmatrix}$$

Here, k is between 0 and 1.

10.3 COLOUR MODELS

Colour spaces or colour models are used interchangeably in image processing. However, there is a subtle difference between these terms. Colour space is a mathematical, virtual model and allows representation, creation, visualization, and reproduction of colours. Colours are represented as a tuple of numbers (mostly three numbers and as four numbers in the CMYK model). A set of colours is described as an abstract mathematical model called a colour model (or colour gamut). The colour model is not associated with any mapping functions connecting its space with the external world. Hence mapping functions are introduced to map the colour model with the reference colour space. Hence, the colour model and the mapping function are together known as the colour space. In this text, the terms colour space and colour models are used interchangeably.

The reference standard is given by CIE standards such as CIEXYZ and its derivatives namely CIELUV and CIELAB. These are known as reference models. The advantages of reference standards are device independence and perceptual linearity.

There are many ways of classifying colour models. One such system of classification is as follows:

Primary systems These are colour models that are based on the trichromatic theory. Examples of primary systems include RGB and CIEXYZ. CIEXYZ is also a reference. RGB is a very popular standard due to the fact that the human visual system is very similar to the RGB model. Some of the disadvantages of the RGB model include its non-linearity (as the addition of a number makes it difficult to predict the resultant colour) and perceptual non-uniformity. RGB models are not intuitive and have high correlation of information among the channels.

Luminance-chrominance systems These systems use one component for luminance and two components for the chrominance part. Examples include $L^*U^*V^*$ and $L^*a^*b^*$.

Perceptual systems These systems try to use quantification of subjective colour perception in terms of intensity, hue, and saturation. Examples include HSV and HLS. The advantage of

HSV, HSI, and HLS is that they are more intuitive and hence are used in many image editing packages. However, the main disadvantage of these systems is their device dependence.

Statistical systems Statistically independent component colour spaces use statistical methods for colour generation. One example is the $I_1I_2I_3$ colour space.

Any colour can be obtained by a combination of red, green, and blue. That is why they are called primary colours. Secondary colours are combinations of primary colours. A colour model is a way of representing a colour with respect to a reference framework. Colour models can be grouped as follows:

1. Additive colour models
2. Subtractive colour models

If the combination of two or more colours results in a new colour with higher luminance, it is called additive colour model. On the other hand, if the combination gives a colour of lower luminance, it is called a subtractive colour model.

In addition, additive models are those where the primary colours are mixed to create any colour. RGB is a good example of an additive colour model. Subtractive models are based on reflected light and use subtractive colours such as cyan, magenta, and yellow to create additional colours. Examples of this category include CMY and CMYK models which are used in the printing industry.

The colour spaces can also be divided based on devices. CIE colour spaces are independent of devices. Device-dependent colour spaces can be categorized into the following:

1. Image-based colour spaces: Examples include RGB, HSV, and HSL.
2. TV-based colour spaces: Examples include YUV and YIQ. TV-based colour models are discussed in Chapter 14.
3. Printer-based colour spaces: Examples include CMY and CMYK.

Every colour space includes a technique for colour representation and a mapping function. Colour space conversion is a process of translating colour information available as a set of points to another model so as to ensure that they look almost similar to the original image.

Example 10.1 Determine the CIE chromaticity coordinates of a point given $C_1 = (0.14, 0.4, 2)$ and $C_2 = (0.51, 0.6, 1)$. Find the third colour C_3.

Solution There are two colours given with three coordinate points. Since the chromaticity diagram is two-dimensional, the intensity is aligned with the Y-axis. The resultant coordinate for the third colour point is given as

$$x_3 = \frac{x_1k_1 + x_2k_2}{k_1 + k_2}$$

$$y_3 = \frac{y_1 k_1 + y_2 k_2}{k_1 + k_2}$$

$$L_3 = L_1 + L_2$$

Here $k_1 = \frac{L_1}{y_1}$ and $k_2 = \frac{L_2}{y_2}$.

The given details are $x_1 = 0.14, y_1 = 0.4, x_2 = 0.51, y_2 = 0.6, L_1 = 2$, and $L_2 = 1$.

Therefore, $k_1 = \frac{L_1}{y_1} = \frac{2}{0.4} = 5,\ k_2 = \frac{L_2}{y_2} = \frac{1}{0.6} \cong 1.67$.

Now the third colour coordinates can be obtained as follows:

$$x_3 = \frac{x_1 k_1 + x_2 k_2}{k_1 + k_2} = \frac{(0.14)(5) + (0.51)(1.67)}{5 + 1.67} \cong 0.23$$

$$y_3 = \frac{y_1 k_1 + y_2 k_2}{k_1 + k_2} = \frac{(0.4)(5) + (0.6)(1.67)}{5 + 1.67} \cong 0.45$$

$$L_3 = L_1 + L_2 = 2 + 1 = 3$$

Therefore, the coordinate of the third colour point will be $(0.23, 0.45, 3)$.

The description of a colour is possible by comparing the colour with the test colour. The experimentation stops when there is a match between the test colour and the combination of test lights. This shows that colour can be expressed as a combination of test colours. This underlying fundamental relationship can be expressed as

$$C = r\mathrm{R} + g\mathrm{G} + b\mathrm{B}$$

Here R, G, and B indicate the red, green, and blue components, respectively. The variables r, g, and b represent the amount of each primary colour component, respectively. This leads to the standardization as defined by the International Commission of Illumination or Commission Internationale de l'Eclairage (CIE), where the idea is to use the colour matching concept to describe any colour.

In 1931, CIE developed such a reference standard for colour representation. This standard ensures that the colours can be produced for devices such as monitors, scanners, and printers in a device-independent manner. The CIE chromaticity diagram, created by CIE, is like a horseshoe-type diagram. What is chromaticity? The components hue and saturation together are called *chromaticity*. As mentioned earlier, the red, green, and blue components are needed to form any particular colour. These are called tri-stimulus values and are denoted by X, Y, and Z. The red components are present along the x-axis, the y-axis is populated by the green components, and the z-axis by the blue components. Every other colour can be represented as a point in the coordinate plane. If the primaries are represented as X, Y, and Z, then any colour can be expressed as

$$C = XX + YY + ZZ$$

where X, Y, and Z are colour vectors of the additive colour space. It is better to normalize the values such that a colour can be defined as

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

Since normalization is done, the sum of x, y, and z is 1, that is, $x + y + z = 1$.

The chromaticity diagram is useful for colour mixing. The points inside the diagram indicate the amount of RGB that can be added to get a specific colour. Thus, any colour inside the triangle can be produced by various combinations of RGB.

The primary colours defined by the chromaticity diagram are red, green, and blue. If the addition of two colours results in white, they are called complementary colours. For example, the complementary colours for red, green, and blue are cyan, magenta, and yellow, respectively. The range of acceptable colours that can be produced in a device is called colour gamut.

We have discussed the CIEXYZ reference model earlier. Another reference model that is useful is called CIE $L^*a^*b^*$ model. This model is an alternative standard with the aim of linearization with respect to human colour perception. It is used by Adobe Photoshop as the standard model for colour space conversions.

L^* is the luminosity, and a^* and b^* are the two colour components that represent the hue and saturation. The components are represented as (X, Y, Z). The reference white point is given as $(X_{\text{ref}}, Y_{\text{ref}}, Z_{\text{ref}})$. The standard CIE XYZ model can be converted to $L^*a^*b^*$ as follows:

$$L^* = 116 * Y' - 16$$

$$a^* = 500 * (X' - Y')$$

$$b^* = 200 * (Y' - Z')$$

where

$$X' = f\left(\frac{X}{X_{ref}}\right), Y' = f\left(\frac{Y}{Y_{ref}}\right), \text{ and } Z' = f\left(\frac{Z}{Z_{ref}}\right)$$

The function $f(c)$ is given as

$$f(c)=\begin{cases} c^{\frac{1}{3}} & \text{for } c>0.008856 \\ 7.787\times c+\dfrac{16}{116} & \text{for } c\le 0.008856 \end{cases}$$

Similarly, the $L^*a^*b^*$ model can be converted to an XYZ model as

$$X = X_{\text{ref}} f\left(\frac{a^*}{500}+Y'\right) Y = Y_{\text{ref}} f(Y')\ Z = Z_{\text{ref}} f\left(Y'-\frac{b^*}{200}\right)$$

where $Y' = L^* + 16/116$. The function is given as

$$f(c)=\begin{cases} c^3 & \text{for } c^3>0.008856 \\ \dfrac{c\times 16/116}{7.787} & \text{for } c^3\le 0.008856 \end{cases}$$

10.3.1 RGB Colour Model

This is the most common format, where the colours are represented in a cube. Each point in the cube is represented by a colour. The origin is represented by black, whereas the opposite corner is represented by white. This model is used in TV, cameras, scanners, and computer monitors. The lines connecting the primaries represent the various shades of the given colour.

Some of the colour shapes are shown in Fig. 10.4.

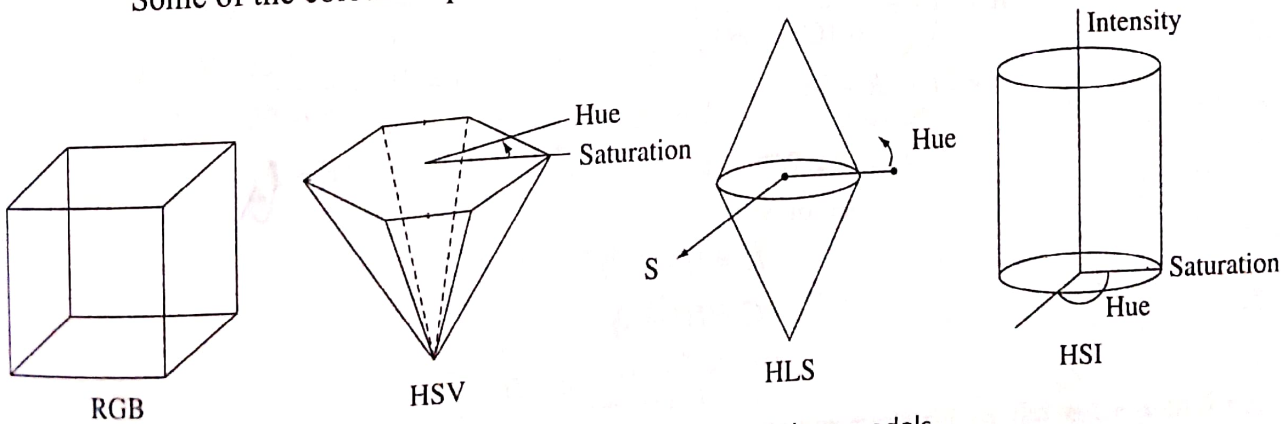


Fig. 10.4 Shapes of colour models

10.3.2 HSI Colour Model

The human perception of colour closely resembles the HSI colour model. Here H represents hue, S represents saturation, and I represents intensity. The component I is the average of the R, G, and B components, and hue is expressed as an angle.

RGB can be converted to HSI using a set of formulae as follows:

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases}$$

with

$$\theta = \cos^{-1}\left\{ \frac{0.5[(R-G)+(R-B)]}{[(R-G)^2 + (R-B)(G-B)]^{\frac{1}{2}}} \right\}$$

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

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

Similarly, the HSI coordinates can be converted to RGB as follows:
Divide 0°–360° into three sectors as

1. sector 1 if H is between 0° and 120°,
2. sector 2 if H is between 120° and 240°, and
3. sector 3 if H is between 240° and 360°.

Based on the sector, compute the components as follows:

Sector 1:

$$B = I(1-S)$$

$$R = I\left(1 + \frac{S\cos H}{\cos(60° - H)}\right)$$

$$G = 3I - (R+B)$$

Sector 2:

$$H = H - 120$$

$$R = I(1-S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right]$$

$$B = 3I - (R+B)$$

Sector 3:

$$H = H - 240$$

$$G = I(1-S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right]$$

$$R = 3I - (G+B)$$

10.3.3 HSV Colour Model

The components of this model are hue, saturation, and value. These components specify the colour. Alternatively, it can be called HSB. Here B is the brightness component. Like the RGB model, this is represented by a six-sided pyramid. The vertical axis is called brightness, the horizontal distance from the axis represents the saturation, and the angle represents the hue.

The RGB model can be converted to the HSV model using the following procedure:

1. Calculate the maximum of the RGB component. This is called k_{max}. The minimum of the RGB component is k_{min}. The range k is given as $k = k_{max} - k_{min}$.
2. The saturation can be calculated as follows:

$$S = \begin{cases} \dfrac{k}{k_{max}} & \text{for } k_{max} > 0; \\ 0 & \text{otherwise} \end{cases}$$

3. The luminance is given as

$$V = k_{max} / r_{max}$$

where r_{max} is the maximum component value as $R, G, B \in [0, \cdots, r_{max}]$

4. Normalize the components as follows:

$$R' = \frac{k_{max} - R}{k}$$

$$G' = \frac{k_{max} - G}{k}$$

$$B' = \frac{k_{max} - B}{k}$$

5. Similarly, the hue can be calculated as follows:

$$H' = \begin{cases} B' - G' & \text{if } R = k_{max} \\ R' - B' + 2 & \text{if } G = k_{max} \\ G' - R' + 4 & \text{if } B = k_{max} \end{cases}$$

The normalized hue is in the range 0–1 and is given as

$$H = \frac{1}{6} \times \begin{cases} (H' + 6) & \text{for } H' < 0 \\ H' & \text{otherwise} \end{cases}$$

For any angle, say 360°, the HSV can be calculated by multiplying the angle with the H value. The plot of the colour components is shown in Fig. 10.5(a) and the conversion of the RGB colour model to the HSV model is shown in Figs 10.5(b) and 10.5(c).

The algorithm for converting the HSV model to RGB model is given as follows:

1. Calculate $H' = (6 \times H) \bmod 6$
2. Calculate

$$x = (1 - S) \times V$$
$$y = (1 - (S \times (H' - \lfloor H' \rfloor)) \times V$$
$$z = (1 - (S \times (1 - H' - \lfloor H' \rfloor))) \times V$$

3. Make a branch based on the value of $\lfloor H' \rfloor$ as follows:

Switch ($\lfloor H' \rfloor$)

Case 0: (v, z, x)

Case 1: (y, v, x)

Case 2: (x, v, z)

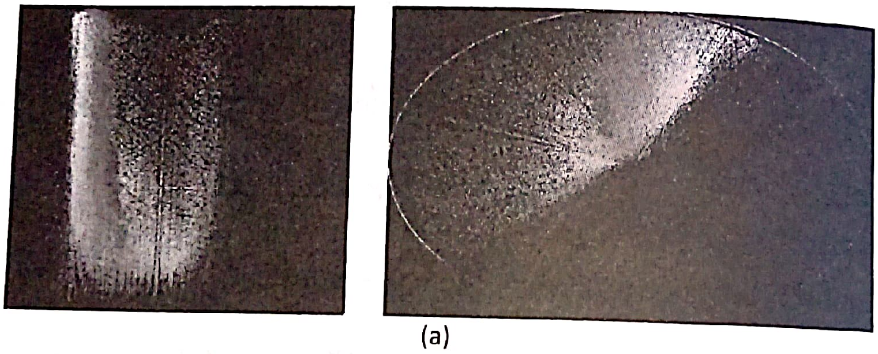
Case 3: (x, y, v)

Case 4: (z, x, y)

Case 5: (v, x, y)

The values can be rounded off as follows:

$$R = \min(\text{round}(R' \times 256), 255)$$
$$G = \min(\text{round}(G' \times 256), 255)$$
$$B = \min(\text{round}(B' \times 256), 255)$$



(a)

(b) (c)

Fig. 10.5 Conversion of RGB model to HSV model (a) Plot of colour components (b) RGB image (c) HSV model (Refer to the OUPI website and Plate 5 for colour images)

Example 10.2 Let the RGB values of a point be (0.4, 0.6, 0.8). Find the HSV equivalent of RGB. In addition, verify whether the original point can be obtained by the inverse transform from HSV to RGB.

Solution Given RGB values are $R = 0.4$, $G = 0.6$, and $B = 0.8$.

$$k_{max} = \max\{R, G, B\} = \max\{0.4, 0.6, 0.8\} = 0.8$$
$$k_{min} = \min\{0.4, 0.6, 0.8\} = 0.4$$
$$k = 0.8 - 0.4 = 0.4$$

Therefore,

$$V = k_{max} = 0.8$$

$$S = \frac{k}{k_{max}} = \frac{0.4}{0.8} = 0.5$$

$$R' = \frac{k_{max} - R}{k} = \frac{0.8 - 0.4}{0.4} = 1$$

$$G' = \frac{k_{max} - G}{k} = \frac{0.8 - 0.6}{0.4} = 0.5$$

$$B' = \frac{k_{max} - B}{k} = \frac{0.8 - 0.8}{0.4} = 0$$

Finally, $H' = G' - R' + 4 = 0.5 - 1 + 4 = 3.5$. Therefore, $\lfloor H' \rfloor = 3$.

Since

$$H' > 0$$

$$H = \frac{1}{6} \times 3.5 = 0.58.$$

Finally the HSV point corresponding to the given RGB point is $(0.58, 0.5, 0.8)$. This can be converted back to RGB. Since $\lfloor H' \rfloor = \lfloor 3.5 \rfloor = 3$, for case 3, the resultant (RGB) is (x, y, v). Here $v = V$. Therefore $V = 0.8$. The remaining values of x and y can be calculated using the given formula:

$$x = (1 - S) \times V = (1 - 0.5) \times 0.8$$
$$= 0.4$$
$$y = (1 - (S \times (H' - \lfloor H' \rfloor))) \times 0.8$$
$$= 0.75 \times 0.8 = 0.6$$

Therefore the original values of RGB are exactly obtained.

.4 HLS Colour Model

The hue, luminance, and saturation (HLS) model is similar to the HSV model. The storage representation of this colour space is a double pyramid, but it is mathematically represented as a cylinder. The hue value of the HLS colour space is similar to that of the HSV colour space.

The procedure of colour space conversion is as follows:

1. The luminance is calculated as

$$L = \frac{k_{max} + k_{min}}{2}; k = k_{max} - k_{min}$$

2. Saturation is given as

$$S = \begin{cases} 0 & \text{for } L = 0 \\ 0.5 \times \dfrac{k}{L} & \text{if } 0 < L \leq 0.5 \\ 0.5 \times \dfrac{k}{1-L} & \text{if } 0.5 < L < 1 \\ 0 & \text{if } L = 1 \end{cases}$$

3. Hue can be calculated as

$$H' = (6 \times H) \bmod 6$$

Similarly, the HLS colour model can be converted to the RGB model using the following procedure:

1. Calculate the parameters

$$m = \begin{cases} S \times L & \text{for } L \leq 0.5 \\ S \times (1 - L) & \text{for } L > 0.5 \end{cases}$$

$$x = L - m$$

$$w = L + m$$

$$y = w - (w - x) \times (H' - \lfloor H' \rfloor)$$

$$z = x + (w - x) \times (H' - \lfloor H' \rfloor)$$

2. Assign the RGB values based on the following condition:

Switch ($\lfloor H' \rfloor$)

Case 0: (w, z, x)

Case 1: (y, w, x)

Case 2: (x, w, z)

Case 3: (x, y, w)

Case 4: (z, x, w)

Case 5: (w, x, y)

Similarly, the normalization of (R', G', B') can be done as in the HSV model.

10.3.5 Printing Colour Models

In this section we shall discuss the CMK and the CMYK colour models that are used extensively in printers.

10.3.5.1 CMK and CMYK models

This is a subtractive model. Subtractive models are used in offset printing, digital printing, painting, and photographic printing. The C stands for cyan, M for magenta, and Y for yellow. If C, M, and Y are mixed, it gives the colour black (K). The transformation from RGB to CMY is given as

$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix} \text{ and } \begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} C \\ M \\ Y \end{pmatrix}$$

CMYK is an alternative model that is used in colour printing, where

$$\begin{aligned} K &= \min(C, M, Y) \\ C &= C - K \\ M &= M - K \\ Y &= Y - K \end{aligned}$$

This is represented mathematically as

$$\begin{pmatrix} C' \\ M' \\ Y' \\ K' \end{pmatrix} = \begin{pmatrix} C-K \\ M-K \\ Y-K \\ K \end{pmatrix}$$

10.4 COLOUR QUANTIZATION

The process of converting a mathematical model to an image is called rendering. During the scene rendering process, the generated tuples of red, green, and blue components may be floating point numbers. Therefore, it is necessary to convert the floating point numbers to binary values before they are either displayed or stored. This process of converting the floating points into binary values is called quantization. There is a need to reduce colours as 24-bit monitors are expensive. In addition, human visual systems have certain implicit imperfections as the human eye cannot recognize millions of colours. So there is a need to pick the best substitutes that can replace the colours of an image. This process of picking the best 256 colours is also called colour quantization process.

All the possible colours are together called colour population. Let us assume that it is in the range [0–(M – 1)]. Given M tuples, the problem is to identify the best K colours that can be representative of the whole colour population. If such colours are found, they can replace the whole population of all possible colours, which is the purpose of colour quantization algorithms. The types of colour quantization algorithms are given in Fig. 10.6.

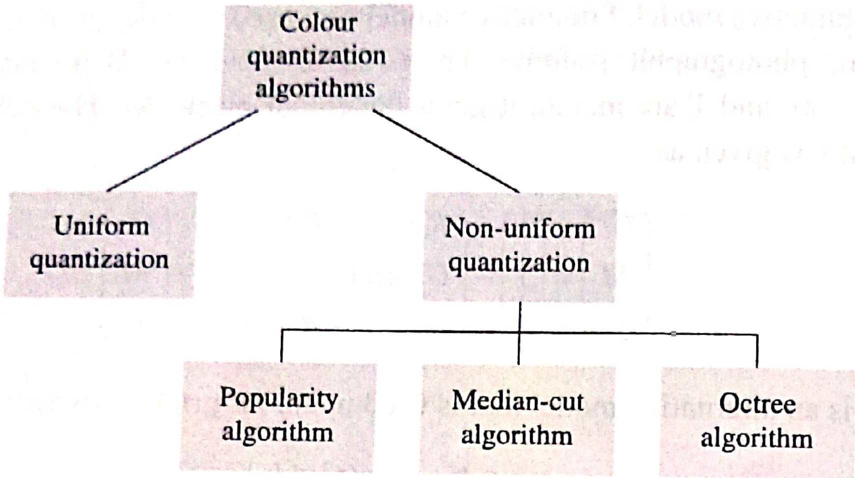


Fig. 10.6 Types of colour quantization

Uniform or *scalar quantization* is a simple technique for colour quantization. Here the range of colours 1–(M – 1) is converted to a new range of colours 1–(K – 1) using the simple formula

$$\text{New colours} = \left[c_i, \frac{K}{M} \right]$$

K is the set of best colours and M is the range of colours. The idea is to slice the colour space along three axes. For example, eight slices of red, eight slices of green, and four slices of blue may yield 256 sub-blocks. The uniform distribution of colours within the colour space, is the optimal condition. However, the distribution of colours is not uniform; hence uniform quantization cannot guarantee the optimal quality of the image. An original image and an image with uniform quantization are shown in Figs 10.7(a) and 10.7(b), respectively.

Non-uniform or *vector quantization* (VQ) techniques treat the colour tuple components as a single entity. The VQ techniques then find the representative colour vectors $\boldsymbol{K} = (C_1', C_2', C_3', \ldots, C_m')$. The representative colours are predetermined using the representative vectors. Some of the important vector quantization algorithms are discussed in Sections 10.5.1–10.5.3.

1 Popularity or Populosity Algorithm

The idea behind this algorithm is to give priority to colours that occur frequently in the image. The procedure for popularity algorithm is as follows:

1. Form a list of colours present in the image.
2. Sort the list based on the frequency of occurrence of the colours.
3. Choose the best K predefined colours in the sorted list.
4. Replace each colour by its closest representative. The closest representative is determined by the mean square distance.

10.4.2 Median-cut Algorithm

Median-cut is a popular algorithm. The idea behind this algorithm is to split the colour space into sub-blocks using the median value such that the sub-blocks have the same colour dots. Generally, the blocks that have the maximum number of colour dots are chosen for the split so that the overall quantization error is low. The procedure for the median-cut algorithm is as follows:

1. Take an original colour cube of the image.
2. Find the median value. Using the median value, split the cube along its longest dimension. The split is such that each block has approximately $N/2$ dots.
3. Repeat step 2, until there are exactly K sub-blocks.
4. For each sub-block, pick a colour representative, which is the centre of the sub-block.
5. Replace the original colour with the representative.
6. Exit.

A queue is a data structure with two ends called the front and rear. It can be compared with a queue in a shop where customers join the queue in one end and are serviced at the other end. Hence, the principle of first-in-first out (FIFO) is maintained. The elements can be added to the rear end of the queue data structure and replaced at the front end. The addition of elements is called the enqueue process and their removal is called the dequeue process. The implementation of the median-cut algorithm is to treat this problem as a queue where after the split, the blocks are enqueued. The block at the front end of the queue is dequeued and the process is applied to it. This procedure is effective, but some bands are still visible. The improved quality of the median-cut algorithm can be visually observed as shown in Fig. 10.7(c).

10.4.3 Octree-based Algorithm

Octree is a data structure where every node has eight children nodes. The nodes have a range of colour space. The idea is to partition the colour space into octree cubic subspaces. The procedure is as follows:

1. Initially the quantization tree is empty. Decide the predefined colours K.

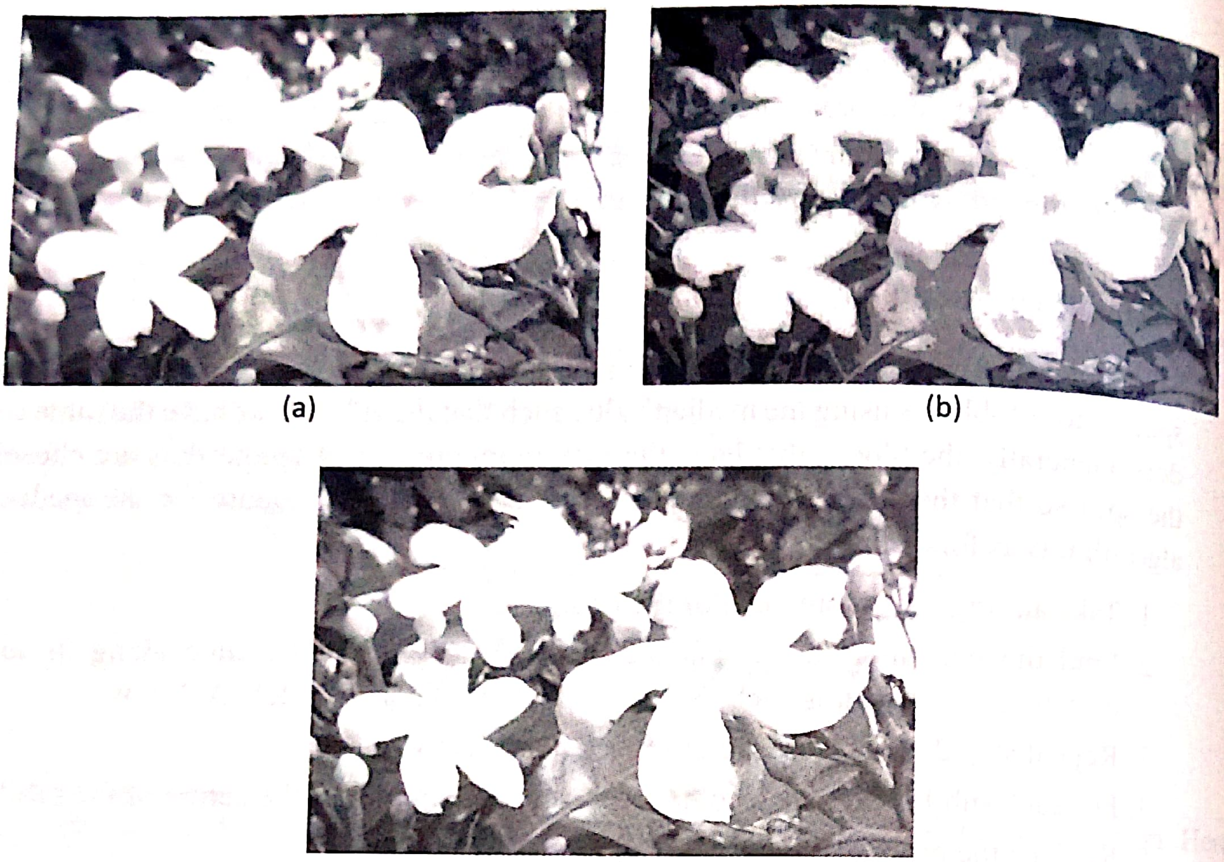


Fig. 10.7 Colour quantization (a) Original image (b) Image with uniform quantization (c) Image after application of median-cut algorithm (Refer to the OUPI website for colour images)

2. Read the colour tuple.
3. Check and insert the colour tuple in the quantization tree. If the colour tuple is not present, then
   (a) If the number of nodes is less than K, create a new node.
   (b) If the number of nodes is K, the existing nodes of similar colour are merged.
4. Replace by locating the best colour in the octree.

The number of colours K is always maintained in the octree and the quantization error is low. Therefore, the image quality is better in this method.

0.5 PSEUDOCOLOUR IMAGE PROCESSING

While colour images are three-band images, multispectral images are multi-band images. A typical remote-sensing image, for example, may have 3–11 bands. The required information is often beyond the human perceptual range. Hence, artificial colour codes are added to these bands so that it is easier for visualization and image analysis.

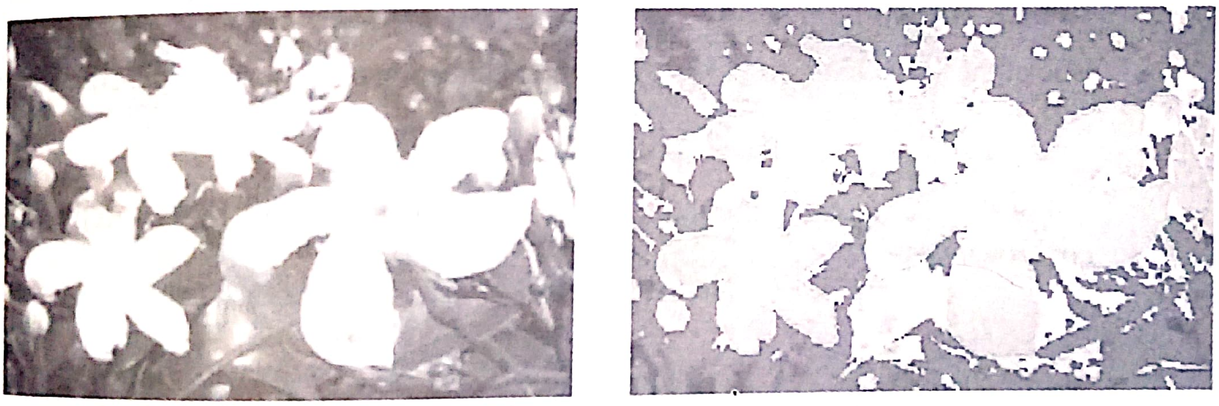
False colour represents a technique of mapping a colour image to another image. Here, the aim is to provide better image contrast for improved display. However, pseudocolour techniques are different. These are techniques that map a grey scale image to a colour image.

Pseudocolouring is done in two stages. In the first stage, the input images are converted into a set of features. In the second stage, the mapping is done so that the grey levels are converted to the colour space. This is done by keeping the value of saturation S a constant. The average of the grey values is mapped to the hue factor.

One way to do this is as follows. Let $f(x, y) = 0$ represent the colour intensity black and $f(x, y) = L - 1$ represent the colour intensity white. The p planes are then defined at levels $L_1, L_2, \ldots, L_p$. The intensity-to-colour assignments are then made such that

$$f(x, y) = C_k \quad \text{if } f(x, y) \in V_k$$

where C_k is a set of valid colours. Now every valid colour is separately applied to the image planes. A sample grey scale image and its pseudocolour image are shown in Figs 10.8(a) and 10.8(b), respectively.



(a) (b)

Fig. 10.8 Pseudocolour image processing (a) Grey scale image (b) Pseudocolour image (Refer to Plate 3 for the colour image)

Another method is to perform intensity-to-colour transformation where the multispectral images are separated into bands. Similar to how colour images are 3-band images, remote sensing images are multi-band images. Thus every band can be extracted and valid colours are assigned individually. These bands are then combined to generate the red, green, and blue components of an image, which drives the display monitor.

10.6 FULL COLOUR PROCESSING

Full or true colour image processing can be done in two ways. One way is to process the red, green, and blue planes individually and then combine them to give a resultant image. Another way is to apply the process directly to the pixels stored in packed component order. These two approaches need not always yield the same answer. The results may be same if the process is applicable to both vectors and scalars. Similarly, if the operation of each component of a vector is independent of the other colour components, the results may be same.

10.6.1 Colour Transformations

The process of mapping the colour from one image to another is called colour transformation. This is different from colour space conversion as colour transforms involve more than a single image.

Colour transformation is of the form

$$g_i = T_i(r_1, r_2, \ldots, r_n), i = 1, 2, 3, \ldots, n$$

where T_i is a set of transformations or colour mapping operations, and $r_1, r_2, \ldots, r_n$ are pixel components. The components vary as per the colour models. For CMYK, the components are r_1, r_2, r_3, r_4. Sections 10.6.1.1–10.6.1.5 discuss some of the types of colour transforms in detail.

10.6.1.1 Intensity modifications

One of the simplest transformations is the modification of intensity. In general, it is of the form

$$g(x, y) = T(f(x, y))$$

For the HSI model, only the intensity component is modified. For RGB models, all the components should be transformed.

$$g_i(x, y) = k \cdot f_i(x, y)$$

For the CMYK colour space, the colour transformation is of the form

$$g_i(x, y) = k \cdot f_i + (1 - k), i = 1, 2, 3$$

However, the output is the same irrespective of the colour model.

Colour images can be enhanced using the following procedure:

1. The RGB components are transformed into another set of colour coordinates.
2. Image enhancement is done for the monochrome grey scale images.
3. After the enhancement is done for the individual grey values, inverse transformation is applied to combine them.

4. The transformed R′G′B′ coordinates are then displayed on the screen.

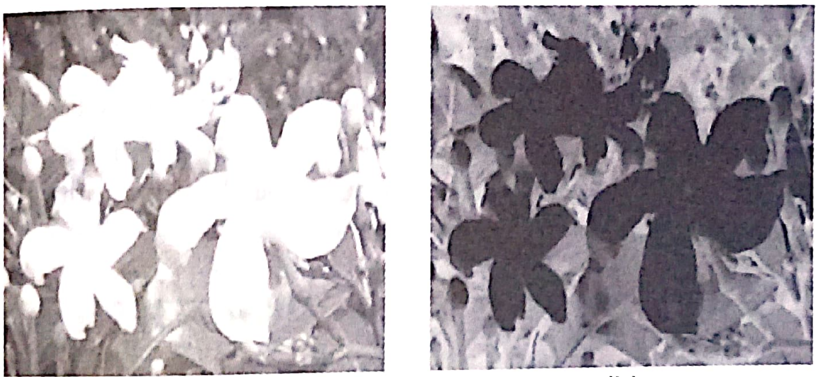
Figures 10.9(a) and 10.9(b) show an original and enhanced colour image, respectively.

(a) (b)

Fig. 10.9 Intensity modification (a) Original colour image (b) Enhanced colour image (Refer to the OUPI website for colour images)

10.6.1.2 *Colour negatives*

The negative of a colour image is used to highlight the components embedded in the dark regions of the image. This is obtained by finding the colour complement of the colour image. An original image and its negative are shown in Figs 10.10(a) and 10.10(b), respectively.



(a) (b)

Fig. 10.10 Colour negative (a) Original image (b) Negative image (Refer to Plate 2 for colour images)

10.6.1.3 *Colour slicing*

Colour slicing is an operation that differentiates an object from its surroundings by highlighting it. The idea is to map the colours that are outside the ROI to a neutral colour. If the colours of interest are enclosed by a cube of width W, the transformation is of the form

$$g_i = \begin{cases} 0.5 & \text{if } \left| |f_i - \text{average}_i| > \dfrac{W}{2} \right| \text{ for } 1 \le i \le n \\ f_i & \text{otherwise} \end{cases}$$

If the colours of interest are enclosed by a mask of the spherical shape, then the transformation is of the form

$$g_i = \begin{cases} 0.5 & \text{if } \sum_{i=1}^{n}(f_i - a_i)^2 > R_0^2 \\ f_i & \text{otherwise} \end{cases}$$

Here R_0 is the radius of the enclosing sphere or hyper sphere and f_i is a pixel of the input image.

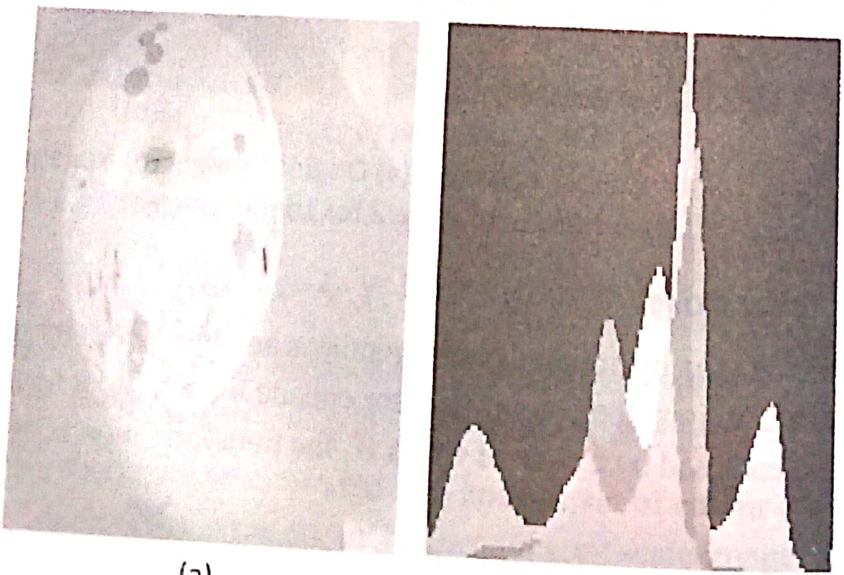
10.6.1.4 Tonal and colour correction

The aim of tonal and colour correction is to correct the tonal and colour imbalances so that the resultant image quality is enhanced. A tonal image is the general distribution of colour intensities. The aim of tonal correction is to distribute the intensities of a colour image equally, such that the intensities in the highlights and shadows are the same. Colour correction refers to rectification of over and under-saturated pixels to improve the quality of the image.

Colour imbalance is another problem. The perception of a colour is affected by the surrounding areas that have different colours. The way to solve this problem is to experiment with the original and complementary colours by increasing or decreasing their percentages. Any change in colour affects the overall balance of the image.

10.6.1.5 Histogram processing

In this process, the histogram for every colour component is calculated and displayed. A colour image and its histogram are shown in Figs 10.11(a) and 10.11(b), respectively. Histograms help in understanding the brightness distribution, contrast, and dynamic range of the colour components.



(a) (b)

Fig. 10.11 Histogram processing (a) Sample image (b) Histogram of colour components (Refer to Plate 2 for colour images)

Similar to how grey scale images are enhanced by histogram processing techniques as discussed in Chapter 5, histograms can also be used to improve colour images. However, if the histogram is equalized, the colour balance is affected, leading to an erroneous colour. Therefore, it is desirable to only spread the colour intensities, while retaining the hue or colours as they are. Histogram processing is simple in the HSI colour space, as processing should be applied to only one intensity component. In addition fewer computations are required. Figures 10.12(a) and 10.12(b) show a low-quality image and its histogram-equalized image, respectively.

(a) (b)

Fig. 10.12 Histogram equalization (a) Original image (b) Histogram-equalized image (Refer to the OUPI website for colour images)

6.2 Image Filters for Colour Images

The process of colour image smoothing is described as follows:

$$f(x,y)=\begin{cases}\dfrac{1}{\lambda}\sum\limits_{(x,y)\in W} R(x,y)\\ \dfrac{1}{\lambda}\sum\limits_{(x,y)\in W} G(x,y)\\ \dfrac{1}{\lambda}\sum\limits_{(x,y)\in W} B(x,y)\end{cases}$$

Similarly, the process of colour image sharpening can be denoted as follows:

$$\nabla^2[f(x,y)]=\begin{cases}\nabla^2[R(x,y)]\\ \nabla^2[G(x,y)]\\ \nabla^2[B(x,y)]\end{cases}$$

Colour image edge detection can be done in the following manner. Let r, g, and b be unit vectors. Assume that these vectors are along the R, G, and B axes, respectively, of an image. The vectors u and v can then be defined as

$$u = \frac{\partial R}{\partial x} r + \frac{\partial G}{\partial x} g + \frac{\partial B}{\partial x} b$$

and

$$v = \frac{\partial R}{\partial y} r + \frac{\partial G}{\partial y} g + \frac{\partial B}{\partial y} b$$

The following components can be defined as

$$g_{xx} = u.u = u^T u = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$

$$g_{yy} = v.v = v^T u = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$

and

$$g_{xy} = u.v = u^T v = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}$$

The direction of the maximum rate of change is given as

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{g_{xx} - g_{yy}}\right]$$

and the rate of change along the direction $\theta(x, y)$ is given as

$$F_\theta(x, y) = \left\{\frac{1}{2}(g_{xx} + g_{yy}) + (g_{xx} - g_{yy})\cos 2\theta(x, y) + 2g_{xy}\sin 2\theta(x, y)\right\}^{\frac{1}{2}}$$

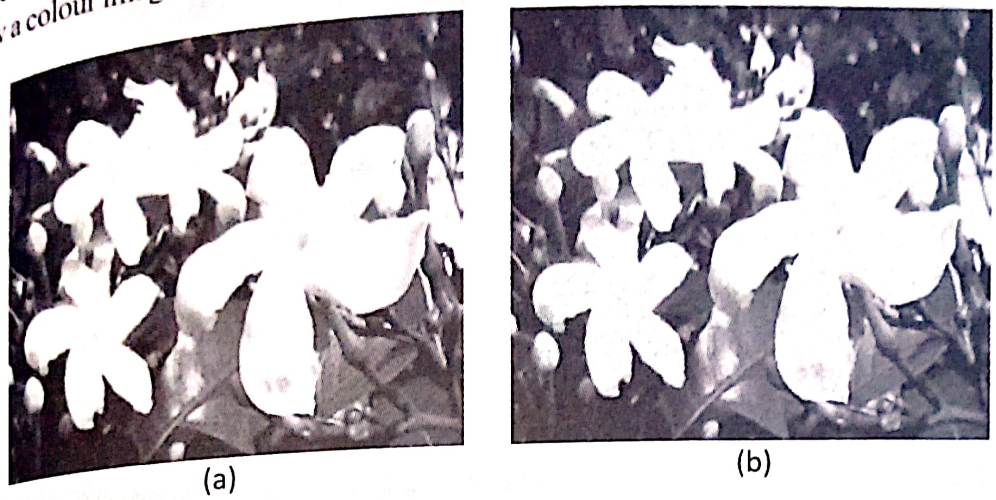
Figures 10.13(a) and 10.13(b) show a colour image and its edges, respectively.

(a) (b)

Fig. 10.13 Colour image edge detection (a) Colour image (b) Edges of the colour image (Refer to Plate 5 for colour images)

10.6.2.1 *Noise in colour images*

The concept of noise in a colour image is same as that of noise in a grey scale image. The processing of colour images to remove noise is also similar. Figures 10.14(a) and 10.14(b) show a colour image and its noisy image. One can observe the loss of quality in the noisy image.



(a) (b)

Fig. 10.14 Noise in colour images (a) Original image (b) Noisy image (Refer to Plate 4 for colour images)

.6.3 Colour Image Segmentation

The extraction of ROI can be done by colour segmentation algorithms using the colour differences among the regions. The ROI can be selected using the thresholding algorithm. Some of the popular colour segmentation methods are as follows:

1. Thresholding
2. RGB colour space segmentation

10.6.3.1 *Thresholding*

Colour images can be thresholded using automatic or semi-automatic thresholding algorithms. The thresholding procedure is given as follows:

1. Read the colour image.
2. Perform the conversion from RGB to YC_bC_r.
3. Find the threshold value.
4. Apply the threshold value to the C_b component only.
5. Display the threshold image.
6. Exit.

Figures 10.15(a) and 10.15(b) show an original image and its thresholded image, respectively.


(a)

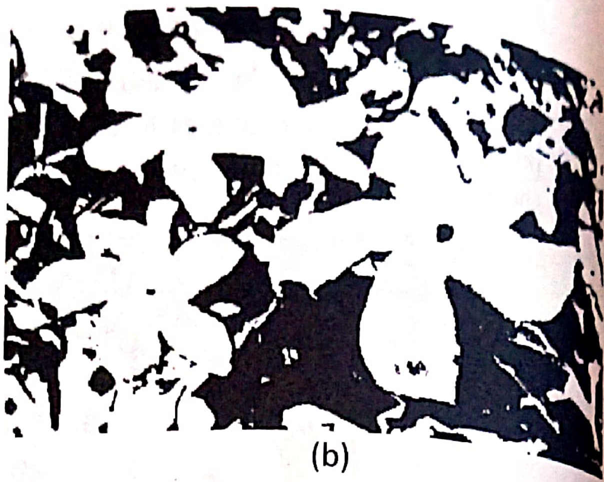

(b)

Fig. 10.15 Thresholding (a) Original image (b) Thresholded image (Refer to the OUPI website for colour images)

10.6.3.2 RGB colour space segmentation

The aim of this method is to use a specific colour range for segmenting the ROI. Let the average colour be denoted by a vector $\boldsymbol{m}$. Let x be an arbitrary point in the RGB space. For image segmentation, the distance between $\boldsymbol{m}$ and x is computed.

$$D(x, \boldsymbol{m}) = \|x - \boldsymbol{m}\|$$

$$= \{(x - \boldsymbol{m})^T (x - \boldsymbol{m})\}^{\frac{1}{2}}$$

$$= [(x_R - \boldsymbol{m}_R)^2 + (x_G - \boldsymbol{m}_G)^2 + (x_B - \boldsymbol{m}_B)^2)^{\frac{1}{2}}$$

The distance is compared with the threshold value. If $D(x, \boldsymbol{m}) \leq$ threshold value, the points belong to the ROI. Otherwise, they are not part of the ROI.

Another useful generalization is to use Mahalanobis distance, which is in the form

$$D(x,\boldsymbol{m}) = [(x - \boldsymbol{m})^T \Sigma^{-1} (x - \boldsymbol{m})]^{\frac{1}{2}},$$ where Σ is the covariance matrix.

Similarly, Euclidean distance can also be used. The distance measures such as Euclidean and Mahalanobis are discussed in Chapter 13.

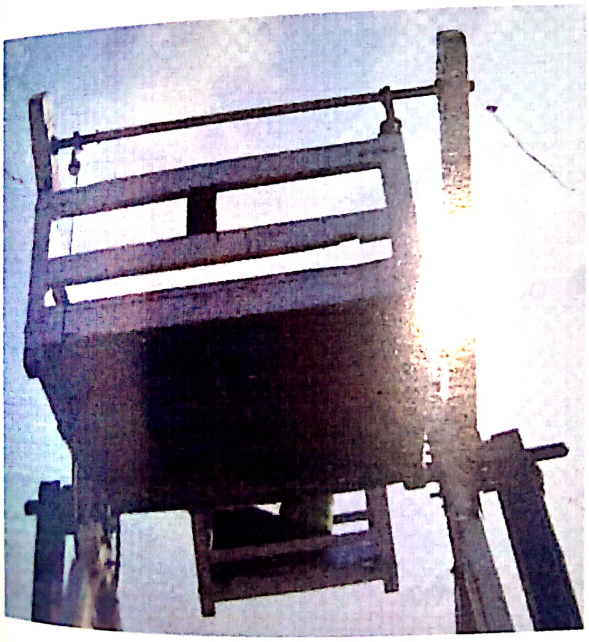
10.6.4 Colour Features

As discussed in the introduction to this chapter, colour is an important descriptor. For identifying the colour of objects, certain features are used. The important colour features are as follows:

Plate 1

Original Picture

Floyd–Steinberg

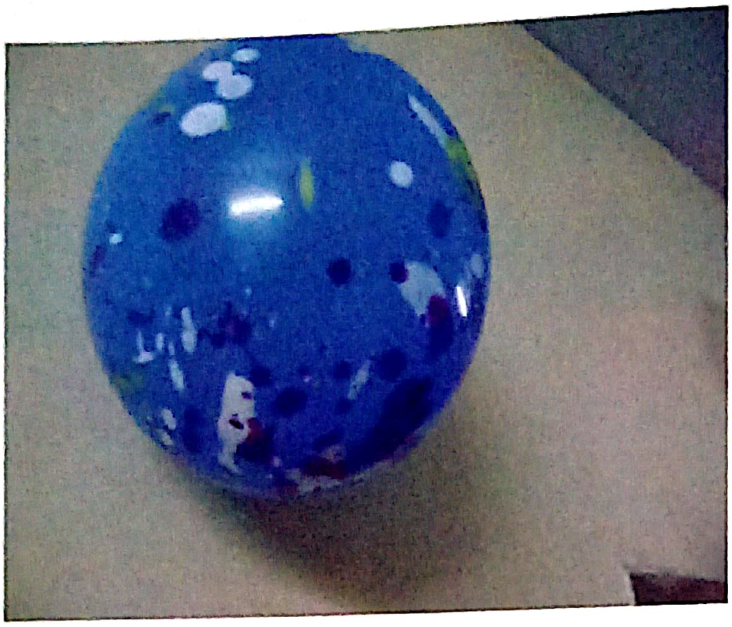


Jarvis–Judice–Ninke

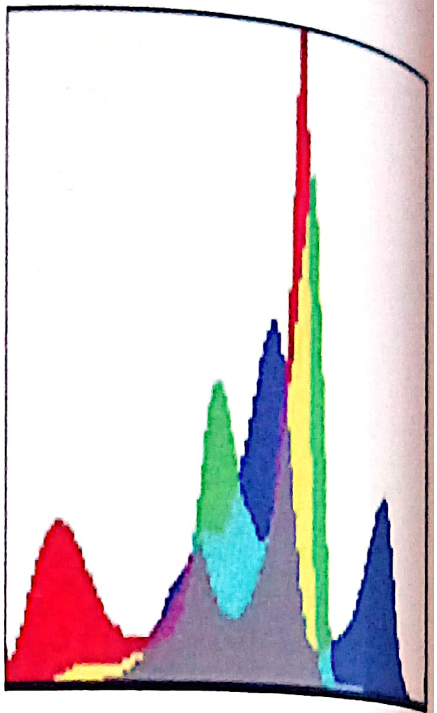
Stucki

Dithering is the process in which noise is added to the input signal before the signal is subjected to the quantization process. Based on the nature of noise, dithering algorithms can be categorized as random, ordered, or non-periodic. This plate shows the results of different dithering algorithms. (Chapter 2, p. 72)

Plate 2



Sample Image



Histogram of Colour Components

In **Histogram processing,** histogram of every colour component is calculated and displayed. Histograms help in understanding the brightness distribution, contrast, and dynamic range of colour components. (Chapter 10, p. 428)

Original Image

Image Negative

The **negative of a colour image** is used to highlight the components embedded in the dark regions of the image. This is obtained by finding the colour complement of the colour image. (Chapter 10, p. 427)

Plate 3

Grey Scale Image

Pseudocolour Image

The purpose of **pseudocolour image processing** is to assign artificial colours to grey-scale images. (Chapter 10, p. 425)

Plate 4

Original Image

Image with Noise

The effect of **noise in colour images** is the same as that of noise in grey-scale images. It can be observed that noise leads to loss of quality in an image. (Chapter 10, p. 431)

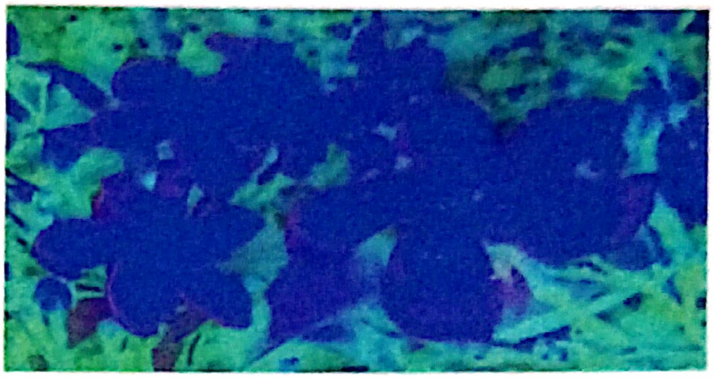
Image with Gamma = 1.5

Image with Gamma = 2.0

Gamma correction is an image enhancement technique based on power law equation as discussed in Chapter 5. The effect of gamma correction for different values of gamma 1.5 and 2.0 is shown in this plate. (Chapter 5, p. 200)

Plate 5

RGB Image



HSV Model

In the **HSV colour model**, the components used to specify the colour are hue, saturation, and value. The picture on the right is the HSV colour space of the RGB image on the left. (Chapter 10, p. 418)

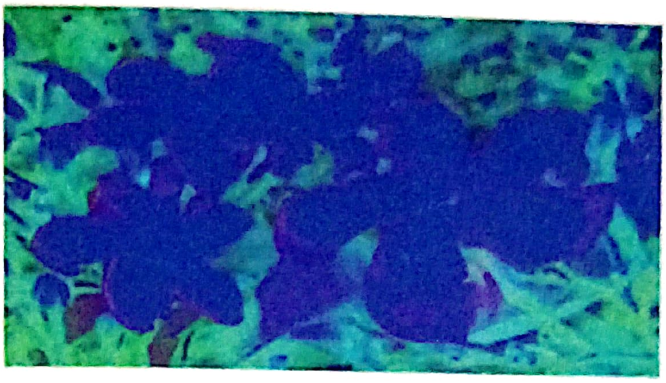
Original Image

Edges of the Image

Colour image edge detection is done for every red, blue, and green component and is fused to give a single edge map. The edges of the original colour image are shown in this plate. (Chapter 10, p. 430)

Plate 5

RGB Image



HSV Model

In the **HSV colour model**, the components used to specify the colour are hue, saturation, and value. The picture on the right is the HSV colour space of the RGB image on the left. (Chapter 10, p. 418)

Original Image

Edges of the Image

Colour image edge detection is done for every red, blue, and green component and is fused to give a single edge map. The edges of the original colour image are shown in this plate. (Chapter 10, p. 430)

Plate 6

Original Picture

Forged Picture

Digital image forensics deals with the detection of forgery in digital images. The picture at the bottom is a forged picture of the original above. It can be observed that some ducks and portions of the wall are missing in the forged picture. (Chapter 14, p. 598)

Plate 7

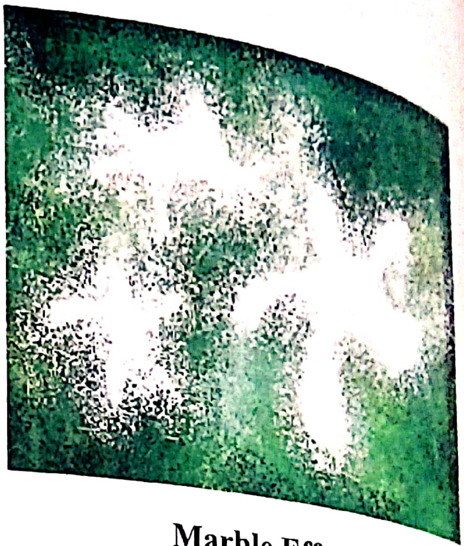
Original Picture

Mosaic of the Original Picture

Image Mosaicking is an operation where every group of pixels is approximated by a given image. In the photomosaic shown above, every rectangular grid is occupied by an image. (Chapter 14, p. 589)

Plate 8

Original Picture



Marble Effect

Pixellation

Embossed picture

Oil effect

Light Effect

Images can be manipulated to create different types of **visual effects**. (Chapter 14, p. 583)

1. Colour histogram—let two histograms, of images A and B, be given as follows:

$$A = \{h_1^A, h_2^A, \ldots, h_K^A\} \text{ and}$$
$$B = \{h_1^B, h_2^B, \ldots, h_K^B\}$$

The similarity between two images is given by the colour distance. Colour distance is given by the measure

$$d = \sum_{j=1}^{k} \left| h_j^A - h_j^B \right|$$

2. The histogram intersection, that is, pixels that are common in two images, is given by

$$I(H^{(A)}, H^{(B)}) = \sum_{j=1}^{k} \min(h_j^A - h_j^B)$$

3. Colour coherence vector—for finding the colour coherence vector, the image can be partitioned into two parts: one part consisting of a count of pixels that belong to a large uniform region and another consisting of the pixels that belong to a sparse region. The colour coherence vector can be represented as a tuple (P, Q), where P is the coherent pixel and Q is the incoherent pixel.
4. Similar to non-colour images, the mean, variance, skewness, kurtosis, and other moments can be identified and detected. The complete details of histogram features are provided in Chapter 10. These image features play an important role in identifying colour images and are mostly used with content-based retrieval systems where colour images are widely used.

SUMMARY

1. Colour is necessary for two reasons—object identification and facilitation of image analysis.
2. Colour is a physiopsychological phenomenon.
3. Human perception of light is characterized by brightness, hue, and saturation. Brightness is the perceived intensity. The dominant wavelength in the spectrum is called hue. The amount of white light present in the spectrum is called saturation.
4. Colour images can be stored in two ways—component ordering and packed ordering.
5. A colour image can be converted to a grey scale image by replacing the RGB values with the luminance value for each pixel.
6. The chromaticity diagram is useful for colour mixing. If the combination of two or more colours results in a new colour with higher luminance, it is called additive colour model. If the combination of colours gives a colour of lower luminance, it is called subtractive colour model.
7. Human perception of colour closely resembles the HSI colour model.
8. In the YIQ model, the Y component represents the grey scale information, whereas the I and Q components represent the colour information.
9. The CMY and CMYK models are subtractive models. Subtractive models are used in offset

printing, digital printing, and photographic printing.

10. During the scene rendering process, the generated tuples of red, green, and blue components may be floating-point numbers. Therefore, it is necessary to convert the floating point numbers to binary values before they are either displayed or stored. This process of converting the floating points into binary values is called quantization.
11. Pseudocolouring is useful for multi-band images.
12. Full or true colour image processing can be done either using packed component order or by processing the colour planes separately.
13. Colour transforms or transformations are mappings of colour from a source image to another resultant image. They deal with operations of a single colour model.
14. The negative of the colour image is used to highlight the components embedded in the dark regions of the colour image. This is obtained by finding the colour complements of a colour.
15. The aim of tonal and colour correction is to correct the tonal and colour imbalances so that the image quality is enhanced. A tonal image is the general distribution of colour intensities. The aim of tonal correction is to also distribute the intensities of a colour image equally so that the intensities are same in the highlights and shadows.
16. The idea behind colour segmentation is to use the colour difference among the regions for segmenting the ROI.

KEY TERMS

Achromatic image A black-and-white image is called achromatic.

Brightness It is the perceived intensity of an image.

Chromatic image A colour image is called a chromatic image.

Chromaticity Hue, saturation, and intensity are together referred to as chromaticity.

Colour depth It is the number of bits used to represent colour.

Colour slicing It is an operation that differentiates an object from its surroundings by highlighting it.

Colour space It is a mathematical model using which colours are represented, created and visualized. The terms colour space and colour model are used interchangeably.

Colour transforms It is the process of mapping colour from one image to another. This is different from colour space conversion as colour transforms involve more than one image.

Component order Colour images that store three identical red, green, and blue components to represent colour information are said to possess information in component order.

Critical fusion frequency It is the frequency at which flicker stops.

Desaturation It is a process of removing the RGB components in a linear manner.

Gamma correction factor It is a factor that is introduced to make the intensity variations linear.

Hue The dominant wavelength in a spectrum is called hue.

Luminance It is the amount of energy emanating from a light source as perceived by the observer.

Palette This is the number of intensity levels supported by the frame buffer.

Pseudocolour image It is an artificially colour-added image.

Rendering It is the process of converting a mathematical model to an image.

Saturation The amount of white light present in a spectrum is called saturation.

Tonal image It is the general distribution of colour intensities.

True colour image A 24-bit colour image is called true colour image.

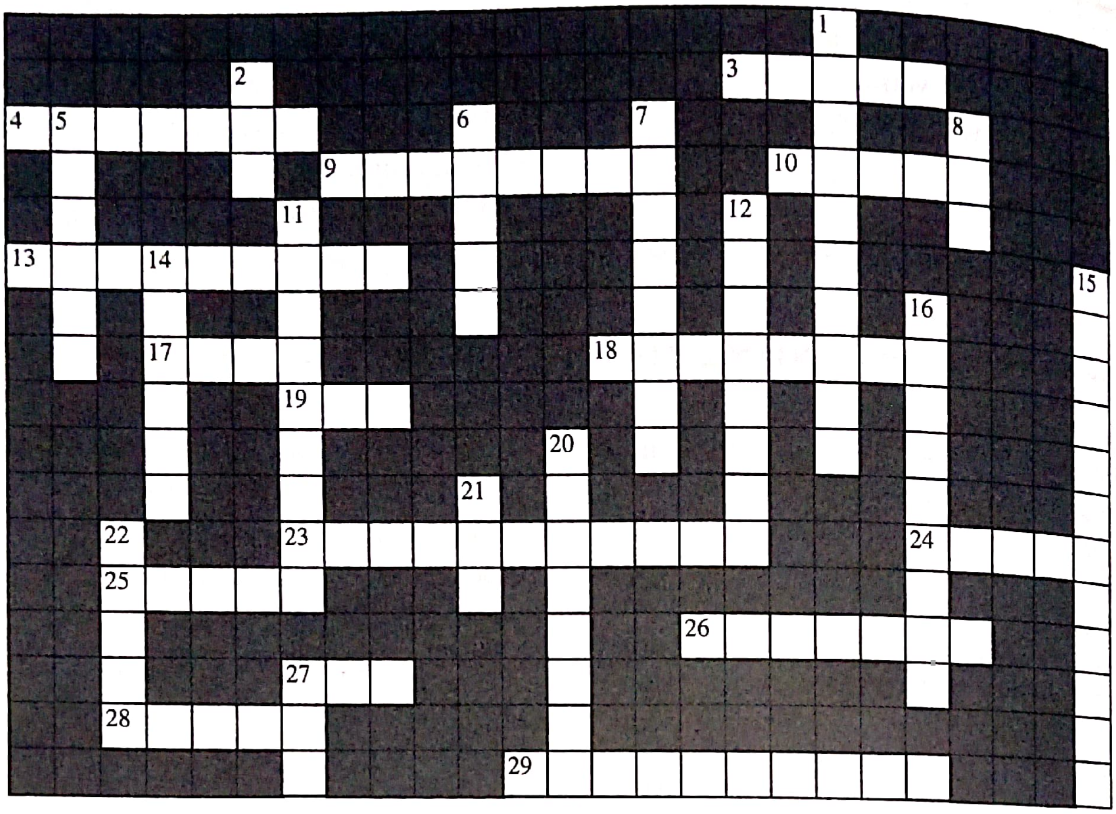
REVIEW QUESTIONS

1. How would you convert a colour image to a grey scale image and vice versa?
2. What is meant by a colour model? Why is it necessary?
3. List the colour models.
4. Explain in detail how the colour models are converted to each other.
5. What is the need for colour transformations?
6. What is the need for colour quantization?
7. What is meant by tonal and colour correction?
8. What is meant by colour segmentation?

NUMERICAL PROBLEMS

1. Consider the following RGB triplets. Convert each triplet to CMY and CMYK.
   (a) (1 0 1)
   (b) (1 1 1)
   (c) (1 0 0)
2. Let the RGB values of a point be (0.2, 0.4, 0.6). Find the HSV equivalent of RGB and also verify whether the original point can be obtained by the inverse transform from HSV to RGB.
3. Determine the CIE chromaticity coordinate of a point given $C_1 = (0.24, 0.6, 2)$ and $C_2 = (0.6, 0.8, 1)$. Find the third colour C_3.

CROSSWORD



Across

3. In CMYK colour model, K stands for _______ colour.
4. CMY and CMYK are _______ based colour models.
9. Populosity algorithms give _______ for colours that occur frequently.
10. Median-cut uses _______ data structure.
13. If colour image is stored as three separate intensity images, it is called _______ ordering.
17. RGB colour model is represented as _______.
18. RGB is an _______ (additive/subtractive) colour model.
19. Human visual system is closer to _______ colour model.
23. An abstract model that describes a set of colours is called _______.
24. RGB colour space segmentation uses a specific colour _______ to segment region of interest.
25. HSV and HSL are _______ based colour models.
26. Colour transform does _______ from one image to another.
27. Colour histogram helps to know dynamic range. (Yes/No)
28. Colour images are _______ band images.
29. Colour is an important feature _______.

Down

1. The purity of light is called _______.
2. Colour is useful for object identification and object highlighting. (Yes/No)
5. Artificial colour addition is done mostly for _______ sensing and medical imaging applications.
6. The general distribution of colours is called a _______ image.
7. HSI colour model is mathematically represented as _______.
8. In remote sensing, bands that are outside human perception are given colours for visualization and analysis. (Yes/No)
11. CIE standard models are called _______ models.
12. Colour models can be grouped as _______ and subtractive colour models.
14. If all colour components are stored together, it is called _______ ordering.
15. Histogram _______ operation gives pixels that are common in two images.
16. The process of converting a model to an image is called _______.
20. The similarity between colours is given by colour _______.
21. Dominant wavelength is called _______.
22. In _______ data structure, every node has eight children.
27. Colour slicing differentiates an object from its surroundings. (Yes/No)

WORD SEARCH PUZZLE

Some of the important terms in this chapter are present in the following word jumble. Identify the words. Diagonal words are possible.

Z	W	B	G	I	R	T	O	N	A	L	Y	B	R	E	N	D	E	R	I	N	G	Y	Z	E
V	T	H	M	V	T	R	J	X	C	O	M	P	O	N	E	N	T	T	X	R	L	J	X	Y
P	Y	J	I	L	L	X	X	C	A	E	A	B	M	P	K	D	A	M	F	F	D	Y	E	E
N	P	J	A	S	C	O	L	O	U	R	S	P	A	C	E	X	Y	K	G	L	N	E	S	S
Z	R	E	N	G	I	M	A	G	E	Y	E	S	B	E	B	E	D	Q	A	V	R	A	O	O
B	I	L	R	C	U	B	E	W	U	Z	G	D	N	F	N	W	Y	R	M	H	S	A	D	B
D	N	F	M	S	Y	Q	Y	E	S	X	R	I	A	A	C	C	R	W	T	P	Z	G	E	J
P	T	B	F	M	A	P	P	I	N	G	V	S	Z	C	Y	L	I	N	D	E	R	E	S	K
A	E	C	U	I	N	T	E	R	S	E	C	T	I	O	N	V	W	T	J	E	V	Y	C	L
C	R	G	A	Q	U	D	J	S	S	Z	W	A	A	U	I	B	M	N	C	I	U	Q	R	N
K	W	W	V	V	U	U	A	N	G	C	Z	N	G	V	P	T	V	R	T	B	F	U	I	E
E	H	M	R	E	F	E	R	E	N	C	E	C	L	K	T	J	T	I	K	L	X	E	P	I
D	N	G	V	O	T	H	R	E	M	O	T	E	S	S	K	Q	D	H	S	A	E	U	T	G
S	S	T	U	R	A	T	I	O	N	X	J	E	N	I	N	D	I	P	D	C	R	E	O	H
M	Y	Q	M	R	A	N	G	E	H	G	Y	X	E	O	A	K	Y	J	Y	K	G	G	R	T
W	R	W	O	X	J	R	G	A	D	D	I	T	I	V	E	W	G	F	B	Z	U	S	B	R
F	E	G	H	U	E	E	Q	E	D	V	Y	J	U	P	R	I	O	R	I	T	Y	T	V	Y

Hints

1. Pseudocolour images are used in _______ sensing applications.
2. ______ ordering is a representation where a pixel has three colour components packed together.
3. The ______ standard is given by CIE standards such as CIE XYZ.
4. ______ colour model is the most natural colour model.
5. The alternative name of colour model is _______.
6. RGB model is a _______ colour model.
7. The dominant wavelength is called _______.
8. The purity or _______ is measured as a percentage of the luminance in the dominant component of the spectrum.
9. Each point of the ______ of RGB model is a colour.
10. HLS colour model is represented mathematically as a _______.
11. Populosity algorithm assigns _______ to each colour that occurs frequently for colour segmentation.
12. Median-cut algorithm uses a _______ as a data structure.
13. In octree, a node can have _______ children.
14. In pseudocolouring, a _______ is done to convert a grey level to the colour space.
15. The aim of _______ correction is to distribute the intensities of colours equally.
16. In histogram _______, the colours that are common in images are used as a feature.
17. Colour _______ are immensely useful for object recognition.