DIGITAL IMAGE PROCESSING

Colour Models: RGB, CMY, HSI & YCbCr

1. Colour Models — Overview

A colour model is a mathematical model used to represent colours as tuples of numbers. It is used in image acquisition, display, storage and processing.

1.1 RGB Colour Model (Additive Model)

- Based on Red, Green and Blue.
- Additive model — colours are created by adding light.
- Used in devices that emit light (monitors, cameras, scanners).
- Each primary component varies from 0 to 1 or 0 to 255.

Black = (0,0,0)   White = (1,1,1) or (255,255,255)
Red = (1,0,0)   Green = (0,1,0)   Blue = (0,0,1)

1.2 CMY Colour Model (Subtractive Model)

- Based on Cyan, Magenta and Yellow.
- Subtractive model — colours are formed by absorbing (subtracting) light.
- Used in printing, paints, inks.
- Each component varies from 0 to 1 or 0 to 100%.

White = (0,0,0)   Black = (1,1,1)
Cyan = (1,0,0)   Magenta = (0,1,0)   Yellow = (0,0,1)

It is the inverse of RGB model: $C = 1 - R$, $M = 1 - G$, $Y = 1 - B$

1.3 HSI Colour Model (Intuitive Model)

- Based on Hue (H), Saturation (S) and Intensity (I).
- Closely matches human perception.
- Useful in image analysis and processing.

Components:

- Hue (H) — Type of colour (dominant wavelength). Range: 0° to 360°
- Saturation (S) — Purity of colour. Range: 0 (grey) to 1 (full colour)
- Intensity (I) — Brightness. Range: 0 (black) to 1 (white)

Gray colours have $S = 0$, any H.
Achromatic axis is along Intensity.

1.4 YCbCr Colour Model

- Also called Luminance – Chrominance model.
- Used in TV, Video compression (JPEG, MPEG).
- Separates brightness (Y) from colour information (Cb, Cr).

- Y represents luminance (grey scale component).
- Cb and Cr represent blue-difference and red-difference chrominance.

Transformation (RGB to YCbCr)

$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$
$$Cb = -0.1687\,R - 0.3313\,G + 0.5\,B + 128$$
$$Cr = 0.5\,R - 0.4187\,G - 0.0813\,B + 128$$

(Range: Y: 0–255, Cb: 0–255, Cr: 0–255)

Cb–Cr Plane (Chrominance)

The Cb–Cr plane places Blue at (0,255), Magenta at (255,255), Cyan at (0,0), Red at (255,0), with Gray (no colour) at the centre point (128,128).

Comparison of Colour Models

Model	Type	Components	Used in	Advantages
RGB	Additive	Red, Green, Blue	Monitors, Scanners, Cameras	Simple, matches display devices
CMY	Subtractive	Cyan, Magenta, Yellow	Printers, Inks, Paints	Good for colour printing
HSI	Intuitive	Hue, Saturation, Intensity	Image Processing, Analysis	Closer to human vision, easy segmentation
YCbCr	Luminance-Chrominance	Y, Cb, Cr	TV, Video Compression	Separates brightness and colour info

Key Points

→ RGB is used for display devices (Additive).
→ CMY is used for printing (Subtractive).
→ HSI corresponds to human visual system.
→ YCbCr separates luminance and chrominance for efficient processing and compression.

2. YCbCr Colour Model (Detailed)

2.1 Introduction

- YCbCr is a colour model widely used in digital image and video processing, especially in TV broadcasting, JPEG, MPEG and image compression.
- It separates the Luminance (brightness) from Chrominance (colour) components.
- This separation allows reduction of redundancy in colour information since the human eye is more sensitive to luminance than to chrominance.

2.2 Components

- Y — Luminance component (brightness). Contains intensity information.
- Cb — Blue-difference chrominance component (difference between Blue and Luma).
- Cr — Red-difference chrominance component (difference between Red and Luma).

Y carries most of the visual information.
Cb and Cr carry only colour (hue) information.

2.3 RGB to YCbCr Conversion

The transformation from RGB to YCbCr is given by the matrix form:

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix}$$

Expanded form:

$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$
$$Cb = -0.169\,R - 0.331\,G + 0.500\,B + 128$$
$$Cr = 0.500\,R - 0.419\,G - 0.081\,B + 128$$

Y in range [0,255]
Cb, Cr in range [0,255] (128 = no colour difference)

2.4 YCbCr to RGB Conversion

The inverse transformation is:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.403 \\ 1 & -0.344 & -0.714 \\ 1 & 1.773 & 0 \end{bmatrix} \begin{bmatrix} Y \\ Cb - 128 \\ Cr - 128 \end{bmatrix}$$

Expanded form:

$$R = Y + 1.403\,(Cr - 128)$$
$$G = Y - 0.344\,(Cb - 128) - 0.714\,(Cr - 128)$$
$$B = Y + 1.773\,(Cb - 128)$$

After computation, clip R, G, B values to [0, 255].

2.5 Colour Space Representation

- YCbCr can be represented in a 3-D space.
- Y-axis is separate from the Cb–Cr chrominance plane.

Centre of chrominance plane (128,128) represents gray (no colour).

2.6 Properties / Advantages

- Separates luminance and chrominance.
- More suitable for compression (subsampling of Cb, Cr).
- Compatible with human visual system (HVS).
- Used in TV systems: PAL / NTSC / SECAM.
- Digital systems: JPEG, MPEG, H.264, H.265.
- Allows grayscale display using only the Y component.

2.7 Sampling / Subsampling (Example)

Because the eye is less sensitive to chrominance, Cb and Cr can be sampled at a lower rate. Common format: 4:2:0 — Y (luminance) is kept at high resolution, while Cb and Cr (chrominance) are sampled at lower resolution to save bandwidth.

2.8 Applications

- Television broadcasting (colour TV).
- Video compression standards (JPEG, MPEG, H.264, HEVC).
- Image and video transmission.
- Digital photography and cameras.
- Used in computer graphics and multimedia systems.

2.9 Summary Table

Component	Symbol	Represents	Range	Remarks
Luminance	Y	Brightness (intensity)	0 – 255	Carries most visual information
Blue-difference	Cb	(B − Y) information	0 – 255	128 = no blue difference
Red-difference	Cr	(R − Y) information	0 – 255	128 = no red difference

KEY POINT TO REMEMBER: YCbCr model separates brightness (Y) from colour (Cb, Cr). It reduces redundancy and is highly effective for compression and transmission of colour images and video.

3. HSI (Hue – Saturation – Intensity) Colour Model

3.1 Introduction

- The HSI colour model represents colours in terms of attributes that correspond more closely to human perception.
- It separates chromatic content (Hue, Saturation) from achromatic content (Intensity).
- Widely used in image processing, colour image analysis, object detection, colour segmentation, etc.
- Hue indicates the type of colour, Saturation indicates the purity, and Intensity indicates the brightness.

3.2 Components

- H (Hue) — Dominant wavelength or colour type (angle in colour circle), 0° to 360°
- S (Saturation) — Purity of colour; measure of distance from the gray axis. Range: 0 (gray) to 1 (pure colour)
- I (Intensity) — Perceived brightness of colour. Range: 0 (black) to 1 (white)

When $S = 0 \rightarrow$ colour is a shade of gray (no hue)
When $I = 0 \rightarrow$ black; when $I = 1 \rightarrow$ maximum brightness

3.3 Geometrical Representation

The HSI model is represented as a double cone (bicone): White at the top (I = 1) and Black at the bottom (I = 0), with Green (120°), Yellow (60°), Red (0°), Magenta (300°), Blue (240°), and Cyan (180°) arranged around the middle hexagon at the equator.

- Hue is measured by the angle θ around the axis.
- Saturation is the radial distance from axis (0 to 1).
- Intensity is the distance along the vertical axis.

3.4 RGB to HSI Conversion

Let R, G, B be in range [0, 1].

Intensity: $I = (R + G + B) / 3$

Saturation: $S = 1 - [3 / (R + G + B)] \times \min(R, G, B)$
$(\text{If } R = G = B = 0 \rightarrow S = 0)$

Hue:
$\theta = \cos^{-1} \{ \frac{1}{2}[(R-G)+(R-B)] / \sqrt{[(R-G)^2 + (R-B)(G-B)]} \}$
$H = \theta, \quad \text{if } B \leq G$
$H = 360° - \theta, \text{ if } B > G$
$(0° \leq \theta < 360°)$

3.5 HSI to RGB Conversion

Given H (in degrees), S, I:

If $0° \leq H < 120°$:
$B = I(1 - S)$
$R = I[1 + (S \cos H) / \cos(60° - H)]$
$G = 3I - (R + B)$

If $120° \leq H < 240°$: $H' = H - 120°$
$R = I(1 - S)$
$G = I[1 + (S \cos H') / \cos(60° - H')]$
$B = 3I - (R + G)$

If $240° \leq H < 360°$: $H' = H - 240°$
$G = I(1 - S)$
$B = I[1 + (S \cos H') / \cos(60° - H')]$
$R = 3I - (G + B)$

Finally, clip R, G, B to the range [0, 1].

3.6 Hue Circle (Top View of Equator)

Around the hue circle: Red at 0°, Yellow at 60°, Green at 120°, Cyan at 180°, Blue at 240°, Magenta at 300°.

- Hue angle increases counter-clockwise from Red (0°).
- Colours on the edge are pure ($S = 1$). The point at centre ($S = 0$) is gray.

3.7 Properties / Advantages

- Separates intensity from chromatic information.
- More intuitive and consistent with human perception.
- Useful for applications where brightness variations are to be ignored.
- Easy to modify intensity without affecting colour.

Widely used in:

- Colour image enhancement
- Colour segmentation
- Object tracking
- Medical and remote sensing images

3.8 Applications

- Colour image segmentation based on hue.
- Illumination invariant analysis.
- Colour based feature extraction.
- Content based image retrieval.
- Medical image analysis (e.g., histopathology).
- Remote sensing and satellite image analysis.
- Computer vision and robotics.
- Video surveillance and object tracking.

3.9 Comparison with Other Models

Model	Components	Separates Luminance?	Intuitive to Human Eye?	Applications
RGB	Red, Green, Blue	No	Moderate	Display devices
CMY/CMYK	Cyan, Magenta, Yellow, Key	No	Moderate	Printing
YCbCr	Luminance + Chrominance	Yes	Good	TV, Compression
HSI	Hue, Saturation, Intensity	Yes	Very High	Analysis, Vision

3.10 Example

Convert the RGB colour (R, G, B) = (0.8, 0.2, 0.2) to HSI:

$I = (0.8 + 0.2 + 0.2)/3 = 0.4$
$S = 1 - [3/1.2](0.2) = 1 - 0.5 = 0.5$
Since $B(0.2) \leq G(0.2)$, *use first case for* θ:
$\cos\theta = \{½[(0.8-0.2)+(0.8-0.2)]\} / \sqrt{[(0.8-0.2)^2 + (0.8-0.2)(0.2-0.2)]} = 0.6/0.6 = 1$
$\theta = \cos^{-1}(1) = 0°$
Hence, $H = 0°$, $S = 0.5$, $I = 0.4$

3.11 Summary Table

Component	Meaning	Range	Interpretation
Hue (H)	Type of colour	0° – 360°	Angle in hue circle
Saturation (S)	Purity of colour	0 – 1	0 = gray, 1 = pure colour
Intensity (I)	Brightness	0 – 1	0 = black, 1 = white

KEY POINT TO REMEMBER: The HSI model represents colour using parameters (H, S, I) that are closer to human perception. It is a powerful model for colour image processing tasks where brightness and colour need to be handled separately.