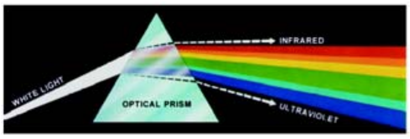
SE3IA11 Image Analysis

Colour Image Processing



Chapter 6 in the Gonzalez & Woods book

Contents in this topic

- Fundamentals of the physical nature of colour
- Colour models
- Pseudocolour images
- Colour transformations
- Colour segmentation
- Smoothing and sharpening in colour images
- Brief introduction of graphics formats

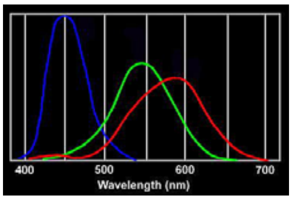
Colour fundamentals

- "Colour" here refers to chromatic light (visible light) in the electromagnetic spectrum from wavelength about 400 to 700 nm.
- Three basic quantities for chromatic light
  - Radiance (measured in watts): the total amount of energy from the light source.
  - Luminance (measured in lumens): a measure of the amount of energy that an observer perceives.
  - Brightness: a subjective descriptor for intensity (grey level).
- Three primary colours
  - Blue (B): 435.8 nm; Green (G): 546.1 nm; Red (R): 700 nm.

Lectured by Hong Wei (Room 145, h.wei@reading.ac.uk)

Three primary colours

- Human eyes do not perceive individual three primary colours separately, but integrate three types of colour receptor (cones) over parts of the spectrum.
- It is possible to characterise a psycho-visual colour by mixing Red, Green, and Blue.



Absorption of light in the human eye as a function of wavelength.
Blue: 445
Green: 535
Red: 575

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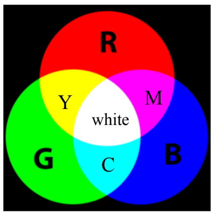
Combination of primary colours

- The secondary colours of light can be generated from R, G, and B.
- They are
  - Magenta (M): R+B
  - Cyan (C): G+B
  - Yellow (Y): R+G
- Additive R, G and B produce white light.



What would it be with additive M, C and Y?

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Characteristics of colours

- Three characteristics of colour light
  - Brightness: intensity not related with colour
  - Hue: the dominant colour perceived by an observer
  - Saturation: the relative purity or the amount of white light mixed with a hue
- Hue and saturation taken together are called *chrominance* (or *chromaticity*).
- A colour can be characterised by *brightness* and *chrominance*.

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Tri-chromatic coefficients

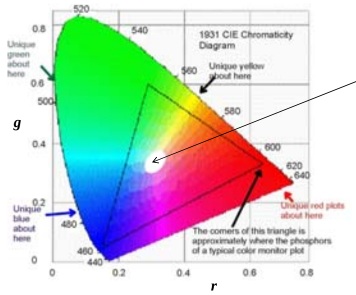
- R, G, and B represent the intensity of red, green and blue to form any particular colours, respectively.
- Tri-chromatic coefficients, r, g, and b are defined as

$$r = \frac{R}{R+G+B} \; ; \; g = \frac{G}{R+G+B} \; ; \text{and} \; b = \frac{B}{R+G+B}$$

- It is noted that

  $r + g + b = 1$
- For any value of r and g, the corresponding value of $b = 1 - (r + g)$.
- R, G, B may be written as X, Y, Z, called tristimulus.

CIE chromaticity diagram



White light (point of equal energy):

$r = 1/3$
$g = 1/3$
$b = 1/3$

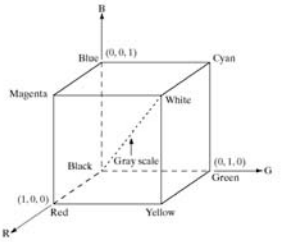
- CIE: Commission Internationale de l'Eclairage (International Commission on Illumination)

Colour models – general

- Definition: a colour model is a specification of a coordinate system and a subspace within that system where each colour is represented by a single point.
- Examples of colour model usage
  - RGB model for colour monitors and colour video cameras
  - CMY model for colour printing
  - HSI model for applications where brightness and chrominance are processed separately.
  - YUV and YIQ models for colour TV systems
  - CIEL*a*b* model to approximate human vision

Colour models – RGB

- The RGB model is represented by a Cartesian coordinate system, mathematically normalised to [0,1].
- The origin is Black.
- The diagonal, starting with Black and ending at White, represents grey scale.
- Different colours are defined by vectors extending from the origin.



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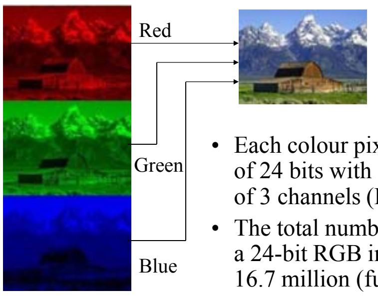
Generating images from the 3 channels



- Each colour pixel has a depth of 24 bits with 8 bits for each of 3 channels (R,G,B).
- The total number of colours in a 24-bit RGB image is about 16.7 million (full colours).

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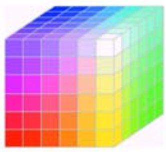
Safe colours *v.s.* full colours

- The 216 safe colours are used for web-page design in the RGB model.
- Each channel can only has values of
  - 0, 51, 102, 153, 204, 255 in decimal or
  - 00, 33, 66, 99, CC, FF in Hexdecimal.

24-bit RGB full colour cube



RGB safe colour cube

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CMY or CMYK colour model

- The CMY model is a subtractive colour model, which is related to the secondary colours of light, and often used in colour printing.
- The CMYK, called "four-colour printing", has the fourth colour "black" added.
- The CMY model can be converted from RGB.

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix} \begin{array}{l} \longrightarrow \text{Taking red out of white} \\ \longrightarrow \text{Taking green out of white} \\ \longrightarrow \text{Taking blue out of white} \end{array}$$

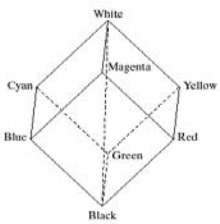
Values of R, G, and B are normalised to the range of [0,1].

The HSI colour model

- HSI stands for Hue, Saturation, and Intensity.
- The HSI model is suited for describing colours.
  - Hue: a colour attribute describing a pure colour.
  - Saturation: a measure of the degree to which a pure colour is diluted by white light.
  - Intensity: a measure corresponding to the subjective descriptor of brightness. It is an achromatic notion.
- Compared to RGB and CMY models, the HSI model is normally used for developing image processing algorithms based on colour descriptions.

The RGB and HSI colour models

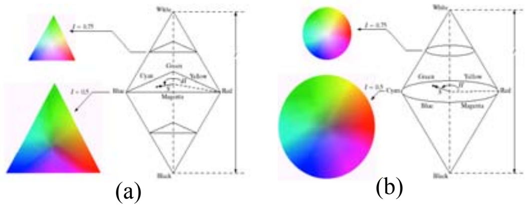
- The intensity axis in the RGB cube is the connected line of the white and black points.
- *Intensity* of a colour point: the intersection of the intensity axis with a plane perpendicular to it and containing the colour point.



- *Saturation*: a colour function of distance from the intensity axis.
- *Hue*: a plane determined by three points – black, white, and a colour point in the cube.

The HSI space

- The HSI space is represented by a vertical intensity axis and colour points that lie on planes perpendicular to this axis.
- In (a), triangular colour planes are used.
- In (b), circular colour planes are used.



(a) (b)

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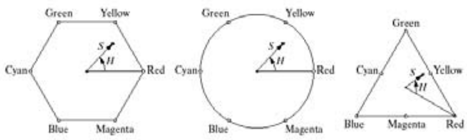
Colour planes in the HSI space

- Values of Hue and Saturation of each colour point can be determined in colour planes.
- Hue is defined as an angle from the red axis.
- Saturation is the length of the vector from the origin to the colour point.



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Converting colours from RGB to HSI

Hue: H; Saturation: S; and Intensity: I

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

R, G, B have been normalised to [0,1].

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

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

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Converting colours from HSI to RGB (1)

There are three sectors based on the value of *H*.

1. *RG sector* ($0^0 \le H < 120^0$)

$$R = I[1 + \frac{S\cos H}{\cos(60^0 - H)}]$$

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

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

Converting colours from HSI to RGB (2)

2. *GB sector* ($120^0 \le H < 240^0$), $H = H - 120^0$

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

$$G = I[1 + \frac{S\cos H}{\cos(60^0 - H)}]$$

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

3. *BR sector* ($240^0 \le H < 360^0$), $H = H - 240^0$

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

$$B = I[1 + \frac{S\cos H}{\cos(60^0 - H)}]$$

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

The YUV colour model

- The YUV colour model is similar to HSI , in which Y represent the brightness and U, V for chrominance.
- The model is used in PAL, NTSC, and SECAM composite colour video standards.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$Y \in [0, 1]$, $U \in [-0.436, 0.436]$, $V \in [-0.615, 0.615]$

The YIQ colour model

- Similar to the YUV model, the YIQ colour model is only used in the NTSC colour TV system.
- Y is for brightness and I, Q represent chrominance.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.595716 & -0.274453 & -0.321263 \\ 0.211456 & -0.522591 & 0.311135 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$R, G, B, Y \in [0,1], \quad I \in [-0.5957, 0.5957], \quad Q \in [-0.5226, 0.5226]$$

The CIEL*a*b* colour model (1)

- The CIEL*a*b* colour model is a device independent model. This means that the colours are defined independent of their nature of creation or the device they are displayed on.
- Its gamut covers the entire visible spectrum and can represent any monitor, printer, and input device.
- Similar to the HSI model, the L*a*b* model decouples intensity (L*) and colour (a* - red minus green, and b* - green minus blue).

The CIEL*a*b* colour model (2)

- Let R, G, B be gray-level of a pixel; and R_w, G_w, and B_w reference white tristimulus values (CIE standard D65 illumination *r*=0.3127, and *g*=0.3290 in the CIE chromaticity diagram).
- The L*, a*, and b* can be calculated as

$$L^* = 116 \cdot h(\frac{G}{Gw}) - 16$$

$$a^* = 500[h(\frac{R}{Rw}) - h(\frac{G}{Gw})]$$

$$b^* = 200[h(\frac{G}{Gw}) - h(\frac{B}{Bw})]$$

where

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

R, G, B are normalised to [0,1].

Pseudocolour image processing

- What is pseudocolour image?
  - Colours of an image are added to each pixel based on a specified criterion rather than from a true colour observation of a scene.
- The operation involved is to assign colours to grey value pixels.
- Applications of pseudocolour image processing mainly contribute to visualisation.

Assigning colours to grey images: intensity slicing (1)

- The information in a 2D grey image pixel consists of intensity (or grey level) and its *x*, *y* coordinates in the image.
- The grey image can be manipulated in a 3D space with intensity *I* as the other coordinate.
- Slicing the 3D space with planes parallel to the *xoy* plane in various intensity levels.
- Intensity between two adjacent levels is assigned a given colour.

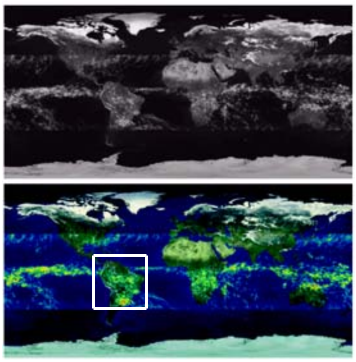
Assigning colours to grey images: intensity slicing (2)

- In summary (in mathematical terms)
  - Let $[0, L\text{-}1]$ represent the grey scale; and
  - l_0 represent black ($f(x,y)=0$) and l_{L-1} represent white ($f(x,y)=L\text{-}1$) .
  - P ($0<P<L\text{-}1$) planes parallel to *xoy* at levels $l_1, l_2, \ldots, l_p$, and divide the grey scale into P+1 intervals $V_1, V_2, \ldots, V_{P+1}$
  - k colours c_k are assigned to the grey image, we have

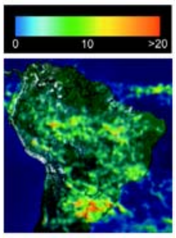
$$f(x,y) = c_k \quad \text{if } f(x,y) \in V_k$$

- It is straightforward!

An example of intensity slicing



Rain-fall map



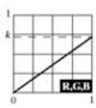
Colour transformation

- Transformation of colour images can be modelled as
  $g(x, y) = T[f(x, y)]$
  - where $f(x,y)$ is an input colour image, $g(x,y)$ the transformed output, and T is the transformation operator.
- Using r_i and s_i for variables denoting the colour components of $f(x,y)$ and $g(x,y)$ at point (x,y), respectively, it can be expressed as
  $s_i = T[r_1, r_2, \ldots, r_n] \qquad i = 1,2,\ldots,n$
- Value n depends on what colour models are selected (process channels separately).
  - RGB: n=3, CMYK: n=4

Example of colour transformation (1)

- Linear transformation in the RGB space.
  - The transformation is done in
    $s_i = kr_i \qquad i = 1,2,3 \quad \text{where } k = 0.7$
  - r_1, r_2, and r_3 represent R, G and B, respectively.
  - s_1, s_2, and s_3 correspond to the transformed output.

Original image Transformed image

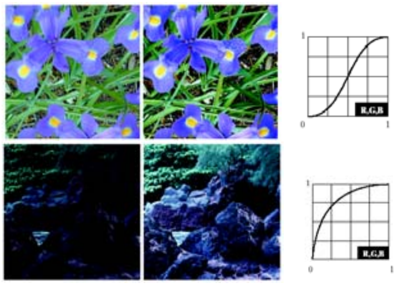


Transformation function

Lectured by Hong Wei (Room 145, h.wei@reading.ac.uk)

Examples of colour transformation (2)

- Non-linear transformation in the RGB space

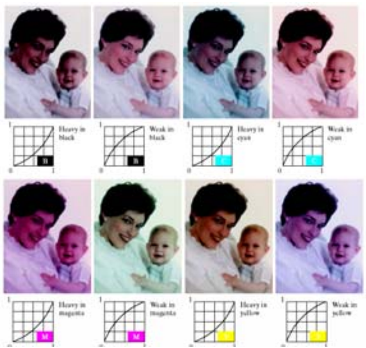


Original Corrected

Example of colour transformation (3)

- Non-linear transformation in the CMYK space

Original image



The colour vector space

- A colour pixel $c(x,y)$ can be represented by a vector as

$$\vec{c}(x,y) = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

- For an image of size $M \times N$, there are $M \times N$ such vectors.
- Results of processing R, G, and B separately are not always equal to those from processing the equivalent colour vectors.

Colour segmentation – 1

- Segmentation in the HSI colour space
  - Separation of chromatic information without intensity influence.
  - Processes on individual planes which are perpendicular to the intensity axis.
- Application: human skin detection
  - Information of "hue" can be used for skin colour detection. This has been used in face and hand detection in human machine interaction.
  - More applications…

Colour segmentation – 2

- Segmentation in the RGB vector space
  - Supervised segmentation which needs a sample RGB vector as a reference.
  - Compare each colour vector of the image to the reference vector, and the distance between two vectors decides the segmentation result.
  - A specified threshod is needed for the distance to judge "true" or "false".
- Applications: separate objects purely based on RGB information.

Mahalanobis Distance

- ***Mahalanobis distance*** is used to identify similarity between an unknown sample set to a known one. Here the sample set is represented by a feature vector.
- It is based on correlations between two samples.
- For two feature vectors $v = (v_1, v_2, \ldots v_N)^T$ and $u = (u_1, u_2, \ldots u_N)^T$, the Mahalanobis distance between them is defined as

$$D_M(v,u) = [(v-u)^T C^{-1} (v-u)]^{1/2}$$

where C is the covariance matrix of v and u.

Colour segmentation – forest inspection

- Try to design algorithms for the following purposes (the L*a*b* model may be used).

Identify burnt area in the forest

Identify smoke/forest fire in the image

Identify bare soil/dead forest

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Smoothing and sharpening

- You have learned detailed techniques and algorithms for image smoothing and sharpening in the topic of image enhancement.
- For colour images, smoothing and sharpening are operated in the colour vector space, *i.e.*

smoothing

$$\bar{c}(x,y) = \begin{bmatrix} \frac{1}{K}\sum_{(x,y)\in S_{x,y}} R(x,y) \\ \frac{1}{K}\sum_{(x,y)\in S_{x,y}} G(x,y) \\ \frac{1}{K}\sum_{(x,y)\in S_{x,y}} B(x,y) \end{bmatrix}$$

and sharpening

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

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Operations of colour image: noise removal and edge detection

- For noise removal, if different noise models are applied to three channels (R, G, B), noise removal can be operated to each of them separately. If there is only one channel is corrupted by noise, when transform to the HSI space, the three channels (H, S, I) are all affected.
- For edge detection based on gradient operation, the colour vector space should be considered. It is not working to separate channel operations.

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Image (graphics) formats: GIF

GIF87a,GIF89a:

- Graphics Interchange Format (GIF) devised by the UNISYS Corp. and Compuserve, initially for transmitting graphical images over phone lines via modems.
- Uses the Lempel-Ziv Welch algorithm for compression.
- Supports only 8-bit (256) colour images.
- GIF89a supports simple animation.

Image (graphics) formats: JPEG

- A standard for photographic image compression created by the Joint Photographics Experts Group (JPEG).
- Takes advantage of limitations in the human vision system to achieve high rates of compression.
- Lossy compression which allows user to set the desired level of quality/compression.

Image (graphics) formats: TIFF

- Tagged Image File Format (TIFF), stores many different types of images (e.g., monochrome, grayscale, 8-bit & 24-bit RGB, etc.).
- Developed by the Aldus Corp. in the 1980's and later supported by Microsoft .
- TIFF is a lossless format (when not utilising the new JPEG tag which allows for JPEG compression).
- It does not provide any major advantages over JPEG and is not as user-controllable.
- It appears to be declining in popularity.

Image (graphics) formats: PDF and BMP

Postscript/ PDF:
- A typesetting language which includes text as well as vector/structured graphics and bit-mapped images.
- Does not provide compression, files are often large.

Windows (BMP):
- A system standard graphics file format for Microsoft Windows.
- It is capable of storing 24-bit bitmap images.
- Used in PC Paintbrush and other programs.

Image (graphics) formats: PNG

- The Portable Network Graphics (PNG) format was designed to replace the older and simpler GIF format and, to some extent, the much more complex TIFF format.
- Advantages over GIF:
  – Alpha channels (variable transparency)
  – Gamma correction (cross-platform control of image brightness)
  – Better Compression (5-25% better)
- Features:
  – Supports three main image types: *truecolour*, *greyscale* and *palette-based* (``8-bit''). JPEG only supports the first two; GIF only the third.

Image (graphics) formats: CGM and SVG

- CGM stands for Computer Graphics Metafile, which is an open international standard file format for 2D vector and raster graphics, as well as text, defined by ISO/IEC 8632.
  – It is independent from software and hardware.
- SVG stands for Scalable Vector Graphics, which is an XML-based vector image format for 2D graphics.
  – Developed by the World Wide Web Consortium
  – Supported by all major modern web browsers

Questions for further thinking

- How to use different colour models in practice? Give examples.
- What is the relationship of colours in various colour spaces? (converting between colour models)
- How to assign colours to a grey-level image?
- How to use colour transformation techniques to enhance images?
- Think about algorithms in image segmentation based on colour information.

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End of the two lectures

- Summary what you have learned in the two lectures.
- Try to use different colour models to represent human skin colours.

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