EART97051 Environmental Data (EDSML) - Earth Observation & Remote Sensing

2 Digital image display, point operations and contrast enhancement

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1

Recommended References

Jian Guo Liu and **Philippa Mason**, 2016, *Image Processing and GIS for Remote Sensing – Techniques and Applications*, Second Edition, 472p (Wiley-Blackwell).

Image processing

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Gonzalez, R. C. and **Rafael**, C., 2002, *Digital Image Processing.*
Mather, P. M., 1999, *Computer Processing of Remotely-Sensed Images.*
Niblack, W., 1986, *An introduction to digital image processing.*
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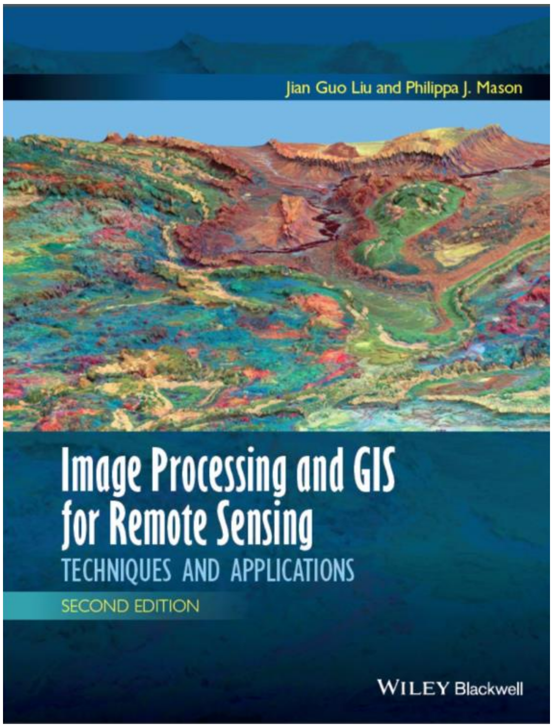
2



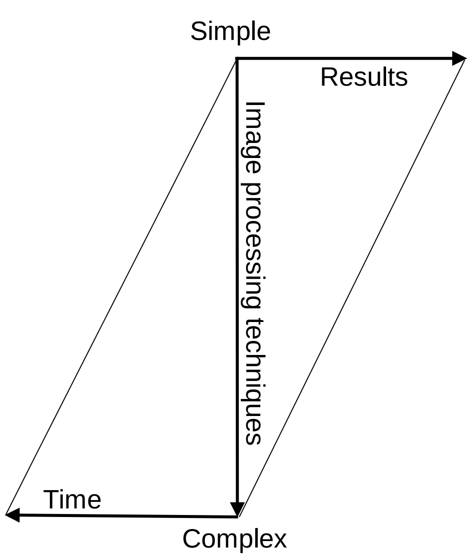
All the mathematical background for image processing of all kinds of digital remotely sensed imagery

ISBN: 978-1-118-72420-0
March 2016, Wiley-Blackwell

Web link for book sale:
http://eu.wiley.com/WileyCDA/WileyTitle/productCd-1118724208.html

3

Image Processing



Warning:
***Image processing can never increase the information contained in the original image dataset*!**

A successful image processing result is not necessarily proportional to the time/effort spent!

On the contrary, you may spend very little time & yet achieve the most useful results with simple techniques OR you could spend a lot of time designing complicated techniques and achieve a very little!

4

Open source developers, APIs, coding, batch-processing, cloud-processing etc

- Github – there is TONS of stuff here to help you get going!
- GEE & Amazon – EO data embedded in these (Sentinels, Landsat)
- Jupiter notebooks (ESE)
- Github stuff - acgeospatial (Andrew Cutts) · GitHub

5

Lecture plan

1. Digital images & monochrome display
2. Tristimulus theory & RGB colour cube
3. Colour composite & pseudocolour display
4. Point operations
5. Common contrast enhancement methods

6

1.1 Digital image display & point operations

1.1.1 Digital (raster) image

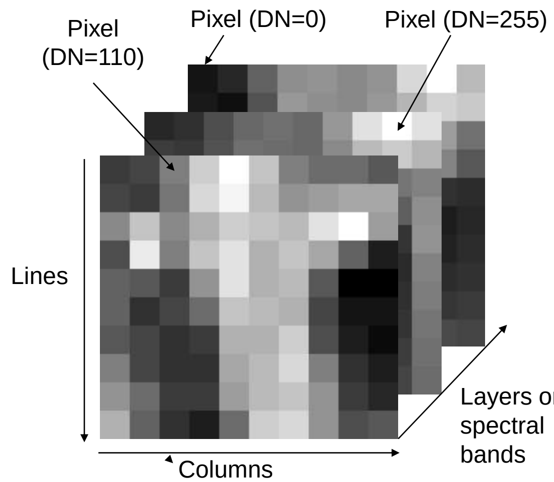
A digital image is a **two dimensional (2D) array** of numbers in lines and columns or a **raster dataset**.

It can also have a 3rd dimension layers (e.g. image spectral bands). Each cell of a digital image is called a **pixel** and the number representing the brightness of the pixel is called a **digital number (DN)**.

A single digital image is **not** a matrix!

Brightness in each pixel is a measure of the selective absorption and reflection of electromagnetic radiation from the ground objects within that pixel, at a particular wavelength.

Digital display allows us to visualise reflected/emitted energy at wavelengths beyond the visible range



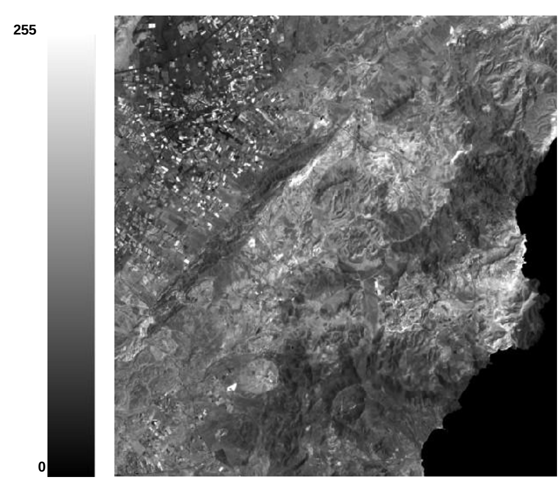
Digital image components

Chapter 1, Digital image and display, Liu & Mason, Image Processing & GIS for remote sensing, Wiley, 2016

7

1.1.2 Monochromatic image display

- Any image (<u>panchromatic image</u> OR <u>a single spectral band of a multi-spectral image</u>) can be displayed as a black and white image via a **monochromatic display**.
- Display is implemented by converting DNs to electronic signals of a series of energy levels to generate different grey levels (degrees of brightness) to form the monochromatic image display.
- Most image processing systems support an 8-bit (256 grey levels) display, i.e. DNs from 0 to 255 (black to white). This display range is wide enough for human visual capacity.
- NB Remotely sensed images may have much wider DN ranges than 8 bits
- e.g. VHR images (Ikonos, QB, WV) often have 11-bit DN range. These images can still be visualised in an 8 bit display system by compressing the DN range, or by displaying the image in several segments of 8-bit intervals across the whole DN range.

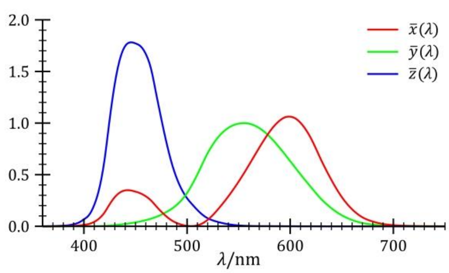


8

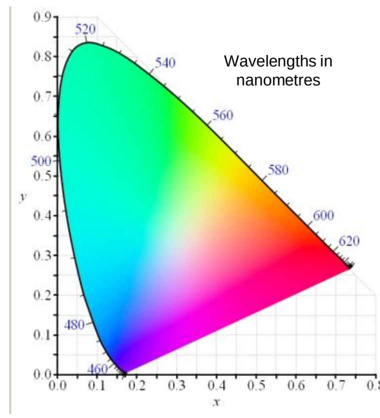
1.1.3 Tristimulus colour theory and RGB colour display

Red, green and blue are referred to as **primary colours**. Human colour perception is performed by three types of cones in the retina with sensitivity peaks matching three primary colours: **R**ed (680 *nm*), **G**reen (545 *nm*) and **B**lue (*440 nm*).

One of the first mathematically defined colour spaces was the CIE (International Commission on Illumination) 1931.



The CIE standard observer colour matching functions



The CIE 1931 colour space chromaticity diagram.

9

1.1.3 Tristimulus colour theory and RGB colour display

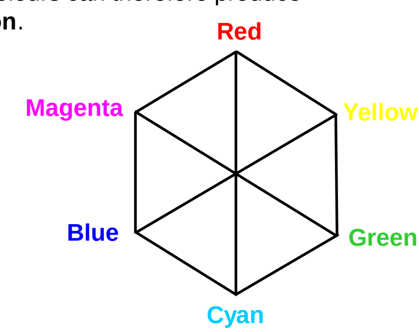
A light of non-primary colour (C) stimulates a different portion of each group of cones to form the perception of this colour. The mixture of the lights of the three primary colours can therefore produce any colours. **This is the principle of RGB additive colour composition**.

$$C = rR + gG + bB$$

Mixtures of equal amount of three primary colours ($r = g = b$) are **white** or **grey**. Equal amounts of any two primary colours generates a **complementary colour**: Yellow, Cyan and Magenta.
These three complementary colours can also be used as primaries to generate various colours as in colour printing.

The 3 geometrically registered colour *guns of a* colour monitor: red, green and blue. In each *gun*, pixels are displayed in tones of differing intensity (e.g. from very dark to very light) depending on their digital numbers (DNs).

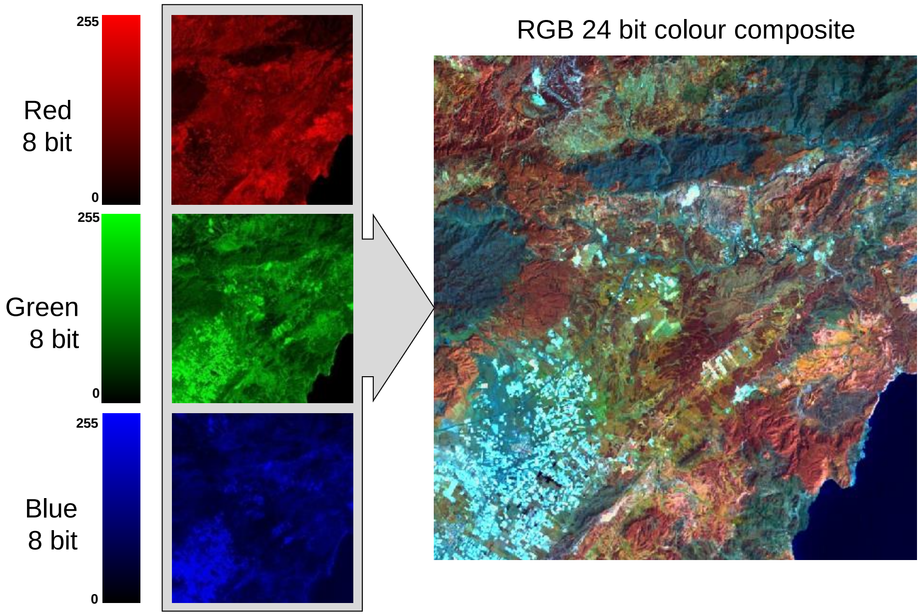
Thus if 3 bands of a multi-spectral image are displayed in red, green and blue simultaneously, a colour image display is generated, in which the **colour of a pixel is decided by its variable DNs in red, green and blue bands (*r, g, b*).** This kind colour display system is called **Additive RGB Colour Composite System**. In this system, different colours are generated by additive combinations of **R**ed, **G**reen and **B**lue components.



Primary colours and their complementary colours.

10

RGB additive colour image display system



11

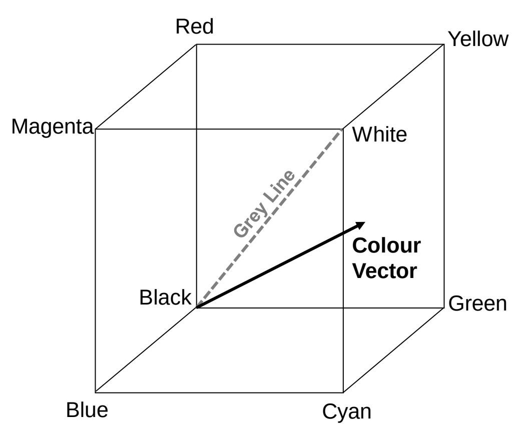
1.1.4 RGB colour cube and colour composites

Consider the components of an RGB display as the orthogonal axes of a 3D colour space where:

- the max possible DN level in each component of the display defines the **RGB colour cube**.

Any image pixel DN is represented by a vector from the origin to somewhere within the colour cube.

Most standard RGB display system can display 8 bits/pixel/channel, giving 24 bits (<16.8 million) different colours.



The line from the origin of the colour cube to the opposite convex corner is known as the **grey line** because pixel vectors that lie on this line have equal components in red, green and blue (*i.e.* $\boldsymbol{r = g = b}$).

12

Revision: True colour composite and false colour composite

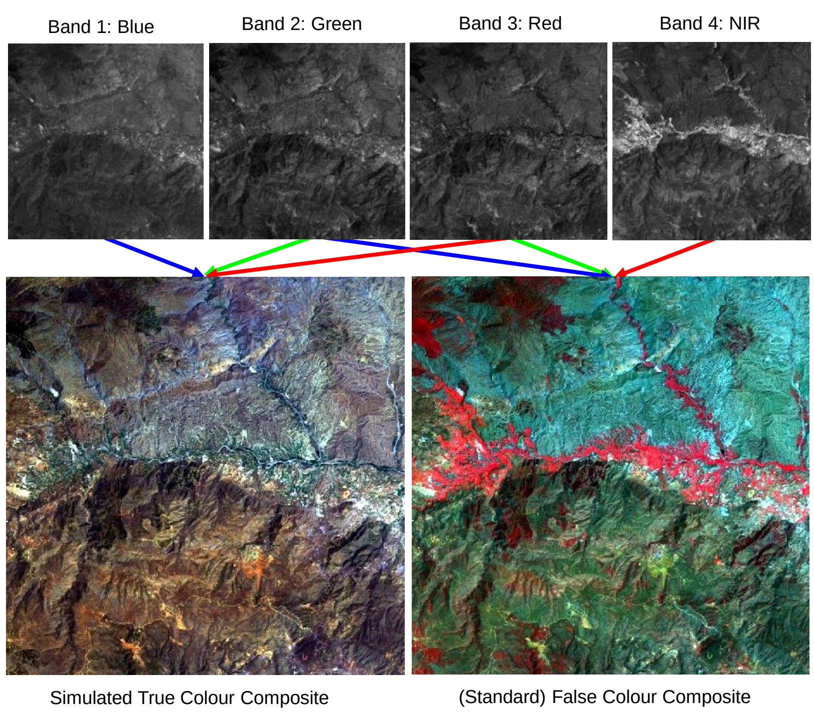
Although colours represent light in the visible spectral range 380-750*nm*, they are also used as a **tool** for visualization in a digital display, as colour images (so we can see the information).

The assignment of each primary colour for a spectral band or layer is arbitrary (depending on the application), and is not necessarily the colour corresponding to the spectral range of the band.

- Simulated **True colour composite** image: display of 3 image bands in red, green and blue spectral ranges in RGB.
- **False colour composite** image: when the image bands displayed in red, green and blue do not match the spectra of these three primary colours.
  - So called '**standard false colour composite'** image where near infrared (NIR) band is displayed in red, red band in green and green band in blue, is a typical example.

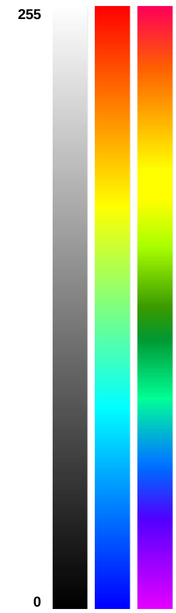
The **false colour composite is the general case of RGB colour display** while the simulated 'true colour composite' is only a **special case** of it.

13



14

1.1.5 Pseudo-colour display



Human eyes recognise far more colours than grey levels - colour may be used more effectively to enhance small brightness differences in a monochrome image.

- Display of a monochrome image in colour = **pseudo-colour display**.
- A pseudo-colour image is generated by assigning each grey level to a unique colour. This can be done by interactive colour editing or by graded colour ramps (there are many possibilities).

The benefit of pseudo colour display can also be a disadvantage…..

- In a greyscale based where DNs are encoded from Black-to-White, the quantitative sequential relationship between different DN values is presented clearly and logically.
- This crucial sequential information can be lost in a pseudo-colour display because the colours assigned to various grey-levels may be not quantitative or sequential, but randomly arranged.

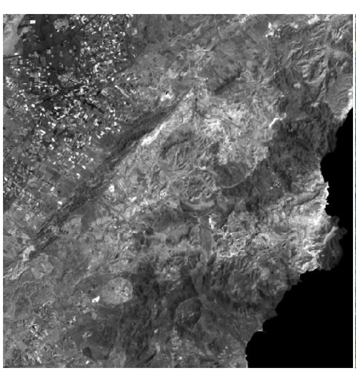
Indeed, the image of a pseudo-colour display is an **image of 'symbols**' rather than numbers; it is no longer a true digital image!

- The **greyscale B/W display as a special case of pseudo-colour** display in which DN are mapped to a sequential greyscale rather than a colour scheme.

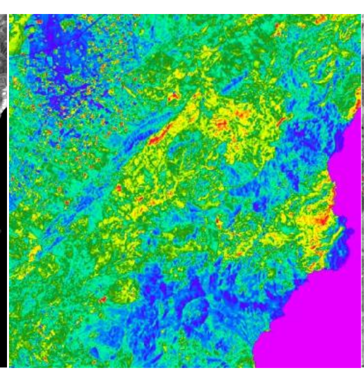
15

Pseudo-colour display

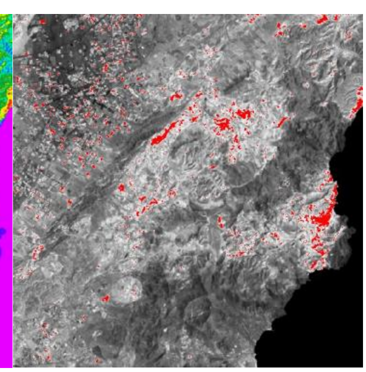
The technique to display a monochrome image as a colour image is called **pseudo-colour display**.



An image in greyscale (B/W) display.



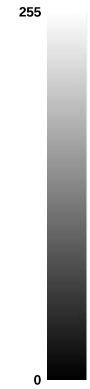
The same image in a pseudo-colour display.



An image in grey scale with the brightest DNs highlighted in pseudo-colours (red in this case)

16

1.2 Point operations (and Contrast enhancement)



- Contrast enhancement, some times called *radiometric enhancement* or *histogram modification*, *etc.*, is the most basic but most effective and efficient technique to optimise the image contrast and brightness for visualization or to highlight information in particular DN ranges.
- Let X represent a digital image and x_{ij} is the DN of a pixel in the image at the i^{th} line and j^{th} column. Let Y represent the output image derived from X by a function f and y_{ij} is the output value corresponding to x_{ij}. Then a contrast enhancement can be expressed in a general form:

$$y_{ij} = f(x_{ij})$$

- This transforms a single input image X to a single output image Y, through a function f, such that the DN of an output pixel y_{ij} depends **only on the DN of the corresponding input pixel x_{ij}**. This is the essence of a **point operation**.
- Contrast enhancement is a point operation that modifies the image brightness and contrast but does not alter the image size or texture.

Chapter 2, Point operations, Liu & Mason, Image Processing & GIS for remote sensing, Wiley, 2016

18

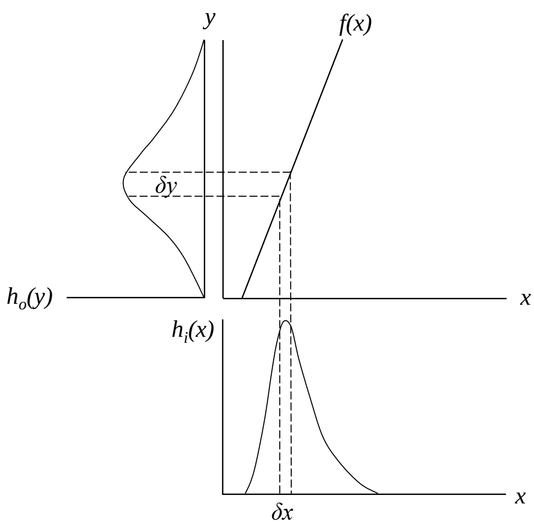
1.2.1 Histogram modification & look up tables (LUT)

- Let x represent a DN level of an image X, then the number of pixels of each DN level, $h(x)$, is the **histogram** of the image X.
- The $h(x)$ can also be expressed as a percentage of the number of pixels of a DN level x against the total number of pixels in the image X. In this respect, in statistical terms, $h(x)$ is a **probability density function**.
- A histogram is a good presentation of **contrast, brightness and data distribution** of an image. Every image has a unique histogram but the reverse is not true in general because a histogram contain no spatial information.
- A point operation could also be called **histogram modification** because the operation only alters the histogram of an image but not spatial relationship of image pixels. For the pixels with the same input DN, x, but different locations, the function f will produce the same output DN, y. Therefore a point operation can be more concisely defined as:

$$y = f(x)$$

19

Principle of a point operation as a histogram modification



$$h_i(x)\delta x = h_o(y)\delta y$$

Let $\delta x \rightarrow 0$ then $\delta y \rightarrow 0$

$$h_o(y) = h_i(x)\frac{dx}{dy}$$

$$= h_i(x)\frac{dx}{f'(x)dx}$$

$$= \frac{h_i(x)}{f'(x)}$$

Or

$$h_o(y) = \frac{h_i(x)}{y'}$$

20

As $f'(x)$ is the gradient of a point operation function $f(x)$, then:

a) when the gradient of a point operation function is **>1**, it is a stretching function which increases the image contrast;

b) when the gradient of a point operation function is **<1** but positive, it is a compressional function which decreases the image contrast.

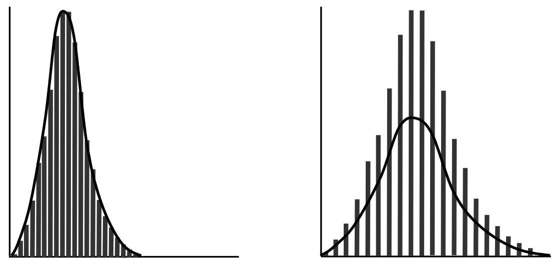
A **non-linear** point operation function can stretch and compress different sections of DN levels depending on its gradient as shown later in the discussion on logarithmic and exponential point operation functions.

In the real case of an integer digital image, both $h_i(x)$ and $h_o(y)$ are **discrete functions**. Given a point operation function $y = f(x)$, the DN level x in the image X is converted to a DN level y in output image Y, and the number of pixels with DN value x in X is equal to that of pixels with DN value y in Y. Thus,

21

$$h_i(x) = h_o(y) \qquad \textbf{???} \qquad h_i(x)dx = h_o(y)dy$$

- The formula on the left is true for a discrete function where $\delta x = \delta y = 1$ as a special case of formula on the right for continuous functions.



Histograms before and after linear stretch (for integer image data)

- The point operation modifies the histogram of a digital image by moving the “histogram bar” of each DN level x to a new DN level y according to the function f.
- Though the histogram bars in the histogram of the stretched image (right) are the same height as those in the original histogram (left), the equivalent continuous histogram drawn as a curve is broader and flatter because of the wider interval between these histogram bars.

22

Look up table (LUT)

- The point operation as a histogram modification can be performed much more efficiently using a look up table (LUT).
- The LUT is composed of DN levels of an input image X and their corresponding DN levels in the output image Y, as shown in this Table.
- When applying a point operation function to enhance an image, firstly the LUT is generated by applying function $y=f(x)$ to every DN level x of the input image X to generate the corresponding DN level y in the output image Y.
  - Then, the output image Y is produced by just replacing x with its corresponding y for each pixel.

An example LUT for a linear point operation function: y=2x-6

x	y
3	0
4	2
5	4
6	6
7	8
8	10
…	…
130	254

23

1.2.2 Linear contrast enhancement (LCE)

$$y = ax + b$$

- LCE is the simplest and one of the most effective contrast enhancement techniques. In this function, a controls the contrast of output images and b modifies the overall brightness.
- LCE improves image contrast without distorting the image information **if the output DN range is wider than the input DN range**. In this case, the LCE does nothing but widen the increment of DN levels and shift histogram position along the image DN axis (it does not change the overall shape).

a) Interactive linear stretch

- Changing *a* and *b* interactively allows optimisation of the contrast and brightness of the output image based on user's visual judgement.

24

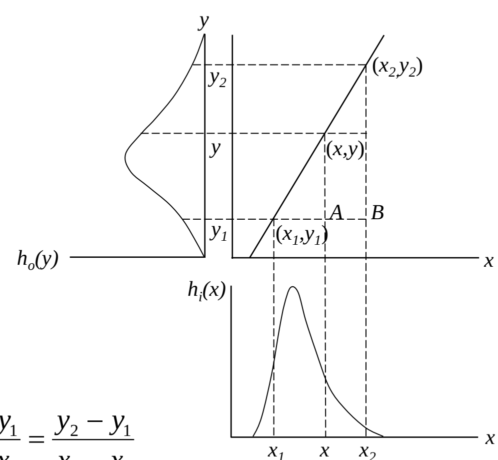
b) Linear scale

- Automatically scale the DN range of an image to the full dynamic range of a display system (8-bit) based on the **maximum and minimum** of the input image X.

$$y = \frac{255[x - Min(x)]}{[Max(x) - Min(x)]}$$

$$\because \Delta(x,y)(x_1,y_1)A \;\; is\ similar \;\; to \;\; \Delta(x_2,y_2)(x_1,y_1)B$$

$$\therefore \frac{y - y_1}{x - x_1} = \frac{y_2 - y_1}{x_2 - x_1}$$

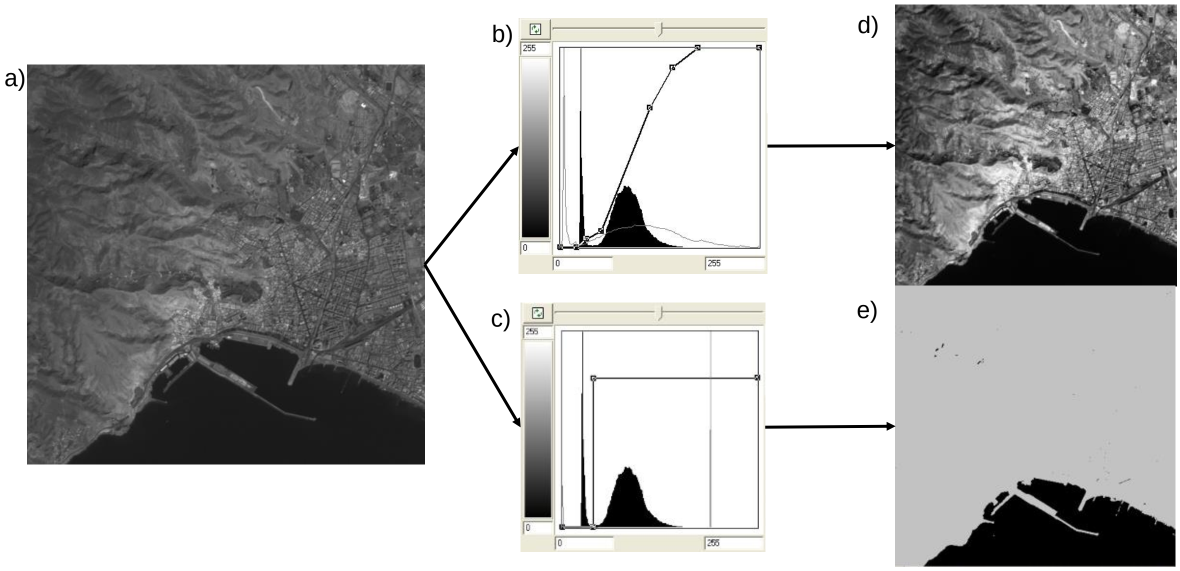


c) Piecewise linear stretch (PLS)

- Use several different linear functions to stretch different DN ranges of an input image. PLS is a very versatile point operation function. It can be used to simulate a non-linear function that cannot be easily defined by a mathematical function.

25

Interactive PLS function for contrast enhancement and thresholding.



a) Original image; b) PLS function for contrast enhancement; c) Enhanced image; d) PLS function for thresholding; e) Thresholded binary image

26

A holiday snap (which just happens to have a few rocks!)

27

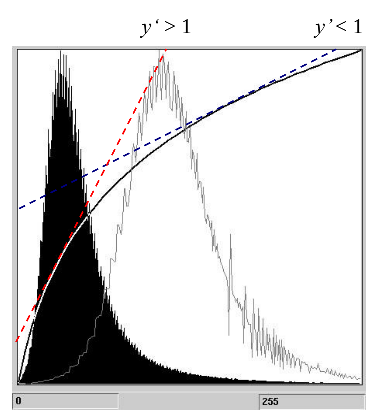
After interactive PLS contrast enhancement

28

1.2.3 Logarithmic & Exponential CE

Logarithmic and exponential functions are the inverse of one another. Both functions change the shapes of image histograms and therefore distort the original image information.

Logarithmic contrast enhancement $y = b\ln(ax+1)$



Here *a* controls the curvature of the logarithmic function while *b* is a scaling factor to make the output DNs within a given value range, and the shift (+1) is to avoid the zero value at which the logarithmic function loses meaning.

Gradient of the function is >1 in the low DN range thus it expands low DN values, and at the high DN range, the gradient of the function is < 1, thus it compresses high DN values.

As a result, logarithmic contrast enhancement shifts the peak of image histogram to the **right** and enhances the details in dark areas of an input image.

Many images have histograms in a form similar to logarithmic normal distribution. In this case, a logarithmic function will modify such a histogram into a shape of normal distribution.

29

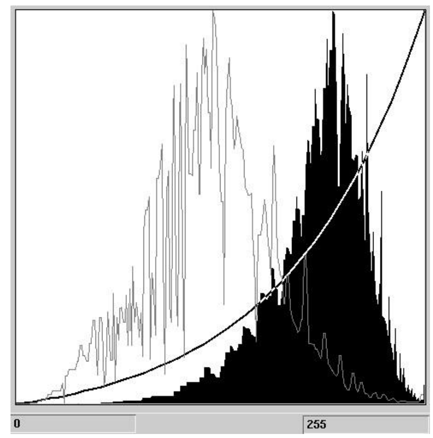
Exponential contrast enhancement $y = b\mathrm{e}^{ax+1}$

Here *a* controls the curvature of the exponential function while *b* is a scaling factor to make the output DNs within a given value range and the exponential shift (+1) is again to avoid the zero value because

$$e^0 = 1$$

As the inverse of the logarithmic function, exponential contrast enhancement shifts the image histogram peak to the **left** by expanding high DN values and compressing low DN values

This enhances image details in bright areas at the cost of suppressing the tone variation in dark areas as illustrated in the figure on the right.



30

Other contrast enhancement techniques

- Histogram equalisation
- Histogram matching
- Gaussian stretch

These distort the image information significantly and **should be avoided** if the actual DN values and their relationships to one another are important

31

1.2.4 Balance Contrast Enhancement Technique

- Colour bias is one of the major causes of poor colour composite images. To eliminate this, the three bands used for colour composition must have an equal value range and mean. The balance contrast enhancement technique (BCET) is a simple solution for this problem.

Parabolic BCET function: $$y = a(x-b)^2 + c$$

- Coefficients *a*, *b* and *c* can be derived based on the **minimum, maximum and mean (*l, h, e*) of the input image *X*** and are the given minimum, maximum and mean (*L, H, E*) for the output image *Y* as below:

$$b = \frac{h^2(E-L) - s(H-L) + l^2(H-E)}{2[h(E-L) - e(H-L) + l(H-E)]}$$

$$a = \frac{H-L}{(h-l)(h+l-2b)}$$

$$c = L - a(l-b)^2$$

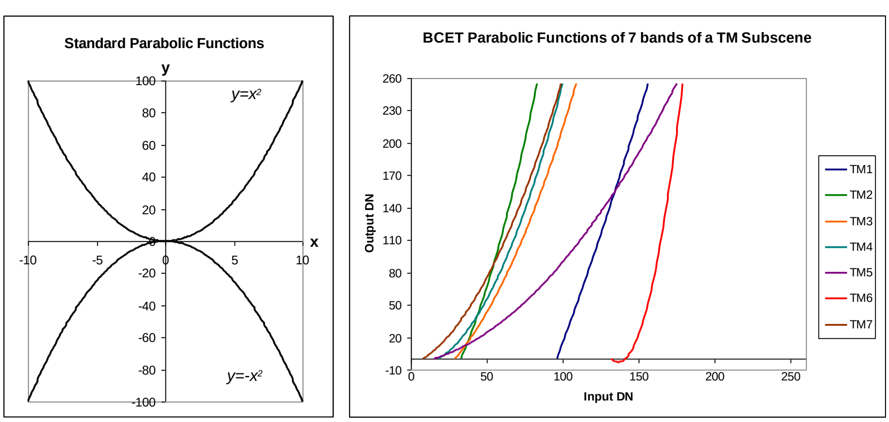
where s is the mean square sum of input image X,

$$s = \frac{1}{N}\sum_{i=1}^{N} x_i^2$$

Liu, 1991. BCET, International Journal of Remote Sensing.

32

- Using the parabolic function derived from an input image, BCET can stretch (or compress) the image to a given value range and mean without changing the basic shape of the image histogram.
- Thus three input image bands for colour composition can be adjusted to the same value range and mean to achieve a balanced colour composite without distorting the image information.

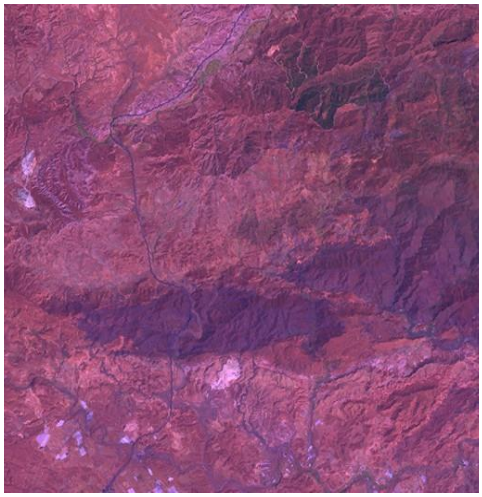


(a) (b)

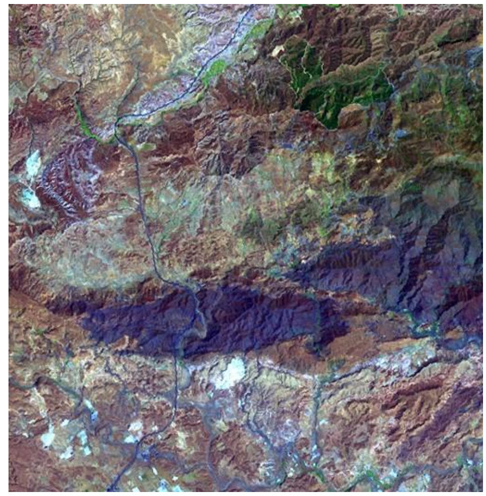
For $b<l$ and $a>0$ = upward curving. For $b>h$ and $a<0$ = downward curving. For $l<b<h$ (e.g b6) BCET fails to avoid the turning point

33

Colour composites of ETM+ bands 5, 4 and 1 in red, green and blue.



Original (un-stretched) bands showing overall magenta cast, caused by colour bias between bands 5, 4 & 1



BCET stretch applied to all bands: providing an equal value range of 0-255 and mean of 110 in each band

34

1.2.5 Cut-off (clipping) in contrast enhancement

- In digital images, a few pixels (often representing noise) may occupy wide value range at the low and high ends of histograms.
- In this case, setting a proper cut-off to clip the both ends of the histogram is necessary in contrast enhancement to make an effective usage of the dynamic range of a display device.
- Clipping is often given as a percentage of total number of pixels in an image.
- For instance, if you set 1% and 99% as the cut-off limits at the low and high ends of the histogram of an image, the image is then stretched to produce an output image which has
  - DN levels $<x_l$, where $H_i(x_l) = 1\%$, set to 0 and
  - DN levels $>x_h$, where $H_i(x_h) = 99\%$, set to 255

  (for a 8 bits/pixel/channel display).

35

1.2.6 Tips for interactive contrast enhancement

- The general purpose of contrast enhancement is to optimise visualization.
- Usually after quite complicated image processing, you still need to apply interactive contrast enhancement to view the results properly.
- After all, **an image is designed to allow you to see the information**.
- Visual observation is always the best way to judge image quality. Although this is seems rather non technical, it is a golden rule and is always very true!
- The histogram is the most effect guide to improving an image's visual quality and the following guidelines for histogram modification may be useful:

36

Golden rules:

1. **Make full use of the dynamic range of the display system**. This can be done by specifying the actually limits of the input image to 0 and 255 for an 8-bit display. Here percentage clipping is useful to avoid large gaps at the two ends of the histogram.
2. **Adjust the histogram such that its peak lies near the centre of the display range**. For most images, the peak can often be slightly skewed toward the left to achieve the best visualization (unless the image is dominated by bright features in which case the peak could skew toward right).
3. **A point operation function modifies an image histogram according to the function's gradient or slope:**

   If gradient =1 (slope = 45°), the function does nothing

   If gradient >1 (slope > 45°), the function stretches

   If gradient <1 (slope < 45°), the function compress

   Therefore it is a common approach to use functions with slope >45° to spread peak section and those with slope <45° to compress the tails at the both ends of the histogram.

37

1.2.7 Revision Questions

1. What is a point operation for image processing, give the mathematical definition?
2. Using a diagram to explain why point operation is also called histogram modification.
3. Given the following point operation functions, derive the output histograms from the input histogram:

$$y = 3x - 8 \qquad y = 2.5x^2 - 3x + 2 \qquad y = \sin(x)$$

4. Explain how logarithmic and exponential functions act on image contrast enhancement?
5. What type of function does a BCET use and how a balanced contrast enhancement is achieved?
6. Try to derive the coefficients, *a*, *b* and *c* in BCET function *.*
7. What is clipping and why is it often essential for image display?

38

39