# Part One

## Image Processing

This part covers the most essential image processing techniques for image visualization, quantitative analysis and thematic information extraction for remote sensing applications. A series of chapters introduce topics with increasing complexity from basic visualization algorithms, which can be easily used to improve digital camera pictures, to much more complicated multi-dimensional transform-based techniques.

Digital image processing can improve image visual quality, selectively enhance and highlight particular image features and classify, identify and extract spectral and spatial patterns representing different phenomena from images. It can also arbitrarily change image geometry and illumination conditions to give different views of the same image. Importantly, *image processing cannot increase any information from the original image data*, although it can indeed optimize the visualization for us to see more information from the enhanced images than from the original.

For real applications our considered opinion, based on years of experience, is that *simplicity is beautiful*. Image processing does not follow the well-established physical law of energy conservation. As shown in Figure P.1, often the results produced using very simple processing techniques in the first 10 minutes of your project may actually represent 90% of the job done! This should not encourage you to abandon this book after the first three chapters, since it is the remaining 10% that you achieve during the 90% of your time that will serve the highest level objectives of your project. The key point is that thematic image processing should be application driven whereas our learning is usually technique driven.



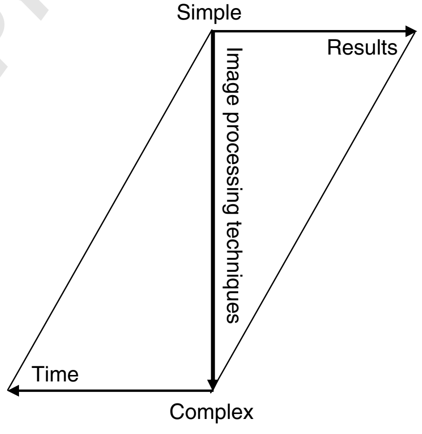


**Figure P.1** This simple diagram is to illustrate that the image processing result is not necessarily proportional to the time/effort spent. On the one hand, you may spend little time in achieving the most useful results and with simple techniques; on the other hand, you may spend a lot of time achieving very little using complicated techniques

# 1

# Digital Image and Display

## 1.1 What is a digital image?

An image is a picture, photograph or any form of a two-dimensional representation of objects or a scene. The information in an image is presented in tones or colours. *A digital image is a two-dimensional array of numbers*. 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) (Figure 1.1). As a two-dimensional (2D) array, a digital image is composed of data in lines and columns. The position of a pixel is allocated with the line and column of its DN. Such regularly arranged data, without $x$ and $y$ coordinates, are usually called *raster data*. As digital images are nothing more than data arrays, mathematical operations can be readily performed on the digital numbers of images. Mathematical operations on digital images are called *digital image processing*.

Digital image data can also have a third dimension: *layer*s (Figure 1.1). Layers are the images of the same scene but containing different information. In multi-spectral images, layers are the images of different spectral ranges called *band*s or *channel*s. For instance, a colour picture taken by a digital camera is composed of three bands containing red, green and blue spectral information individually. The term 'band' is more often used than 'layer' to refer to multi-spectral images. Generally speaking, geometrically registered multi-dimensional datasets of the same scene can be considered as layers of an image. For example, we can digitize a geological map and then co-register the digital map with a Landsat thematic mapper (TM) image. Then the digital map becomes an extra layer of the scene beside the seven TM spectral bands. Similarly, if we have a dataset of a digital elevation model (DEM) to which a SPOT image is rectified, then the DEM can be considered as a layer of the SPOT image beside its four spectral bands. In this sense, we can consider a set of co-registered digital images as a three-dimensional (3D) dataset and with the 'third' dimension providing the link between image processing and GIS.

A digital image can be stored as a file in a computer data store on a variety of media, such as a hard disk, CD, DVD or tape. It can be displayed in black and white or in colour on a computer monitor as well as in hard copy output such as film or print. It may also be output as a simple array of numbers for numerical analysis. As a digital image, its advantages include:

- The images do not change with environmental factors as hard copy pictures and photographs do.
- The images can be identically duplicated without any change or loss of information.
- The images can be mathematically processed to generate new images without altering the original images.
- The images can be electronically transmitted from or to remote locations without loss of information.

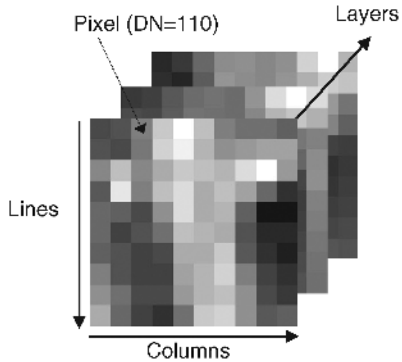


**Figure 1.1** A digital image and its elements

Remotely sensed images are acquired by sensor systems onboard aircraft or spacecraft, such as Earth observation satellites. The sensor systems can be categorized into two major branches: *passive sensors* and *active sensors*. Multi-spectral optical systems are passive sensors that use solar radiation as the principal source of illumination for imaging. Typical examples include across-track and push-broom multi-spectral scanners, and digital cameras. An active sensor system provides its own mean of illumination for imaging, such as synthetic aperture radar (SAR). Details of major remote sensing satellites and their sensor systems are beyond the scope of this book but we provide a summary in Appendix A for your reference.

## 1.2 Digital image display

We live in a world of colour. The colours of objects are the result of selective absorption and reflection of electromagnetic radiation from illumination sources. Perception by the human eye is limited to the spectral range of 0.38–0.75 µm, that is a very small part of the solar spectral range. The world is actually far more colourful than we can see. Remote sensing technology can record over a much wider spectral range than human visual ability and the resultant digital images can be displayed as either black and white or colour images using an electronic device such as a computer monitor. In digital image display, the tones or colours are visual representations of the image information recorded as digital image DNs, but they do not necessarily convey the physical meanings of these DNs. We will explain this further in our discussion on false colour composites later.

The wavelengths of major spectral regions used for remote sensing are listed below:

| | |
|---|---|
| Visible light (VIS) | 0.4–0.7 µm |
| Blue (B) | 0.4–0.5 µm |
| Green (G) | 0.5–0.6 µm |
| Red (R) | 0.6–0.7 µm |
| Visible–photographic infrared | 0.5–0.9 µm |
| Reflective infrared (IR) | 0.7–3.0 µm |
| Nearer infrared (NIR) | 0.7–1.3 µm |
| Short-wave infrared (SWIR) | 1.3–3.0 µm |
| Thermal infrared (TIR): | 3–5 µm, 8–14 µm |
| Microwave | 0.1–100 cm |

Commonly used abbreviations of the spectral ranges are denoted by the letters in brackets in the list above. The spectral range covering visible light and nearer infrared is the most popular for broad-band multi-spectral sensor systems and it is usually denoted as VNIR.

### 1.2.1 Monochromatic display

Any image, either a panchromatic image or a spectral band of a multi-spectral image, can be displayed as a black and white (B/W) image by a monochromatic display. The display is implemented by converting DNs to electronic signals in a series of energy levels that generate different grey tones (brightness) from black to white, and thus formulate a B/W image display. Most image processing systems support an 8 bit graphical display, which corresponds to 256 grey levels, and displays DNs from 0 (black) to 255 (white). This display range is wide enough for human visual capability. It is also sufficient for some of the more commonly used remotely sensed images, such as Landsat TM/ETM+, SPOT HRV and Terra-1 ASTER VIR-SWIR (see Appendix A); the DN ranges of these images are not wider than 0–255. On the other hand, many remotely sensed images have much wider DN ranges than 8 bits, such as those from Ikonos and Quickbird, whose images have an 11 bit DN range (0–2047). In this case, the images can still be visualized in an 8 bit display device in various ways, such as by compressing the DN range into 8 bits or displaying the image in scenes of several 8 bit intervals of the whole DN range. Many sensor systems offer wide dynamic ranges to ensure that the sensors can record across all levels of radiation energy without localized sensor adjustment. Since the received solar radiation does not normally vary significantly within an image scene of limited size, the actual DN range of the scene is usually much narrower than the full dynamic range of the sensor and thus can be well adapted into an 8 bit DN range for display.

In a monochromatic display of a spectral band image, the brightness (grey level) of a pixel is proportional to the reflected energy in this band from the corresponding ground area. For instance, in a B/W display of a red band image, light red appears brighter than dark red. This is also true for invisible bands (e.g. infrared bands), though the 'colours' cannot be seen. After all, any digital image is composed of DNs; the physical meaning of DNs depends on the source of the image. A monochromatic display visualizes DNs in grey tones from black to white, while ignoring the physical relevance.

### 1.2.2 Tristimulus colour theory and RGB colour display

If you understand the structure and principle of a colour TV tube, you must know that the tube is composed of three colour guns of red, green and blue. These three colours are known as *primary colours*. The mixture of the light from these three primary colours can produce any colour on a TV. This property of the human perception of colour can be explained by the *tristimulus colour theory*. The human retina has three types of cones and the response by each type of cone is a function of the wavelength of the incident light; it peaks at 440 nm (blue), 545 nm (green) and 680 nm (red). In other words, each type of cone is primarily sensitive to one of the primary colours: blue, green or red. A colour perceived by a person depends on the proportion of each of these three types of cones being stimulated and thus can be expressed as a triplet of numbers ($r$, $g$, $b$) even though visible light is electromagnetic radiation in a continuous spectrum of 380–750 nm. A light of non-primary colour $C$ will stimulate different portions of each cone type to form the perception of this colour:

$$C = rR + gG + bB. \tag{1.1}$$

Equal mixtures of the three primary colours ($r = g = b$) give white or grey, while equal mixtures of any two primary colours generate a complementary colour. As shown in Figure 1.2, the complementary colours of red, green and blue are cyan, magenta and yellow. The three complementary colours can also be used as primaries to generate various colours, as in colour printing. If you have experience of colour painting, you must know that any colour can be generated by mixing three colours: red, yellow and blue; this is based on the same principle.

Digital image colour display is based entirely on the tristimulus colour theory. A colour monitor, like a colour TV, is composed of three precisely registered colour guns, namely red, green and blue. In the red gun, pixels of an image are displayed in reds of different intensity (i.e. dark red, light red, etc.) depending on their DNs. The same is true of the green and blue guns. Thus if the red, green and blue bands of a multi-spectral image are displayed in red, green and blue simultaneously, a colour image is generated (Figure 1.3) in which the colour of a pixel is decided by the DNs of red, green and blue

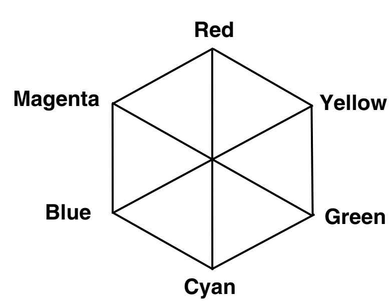


**Figure 1.2** The relation of the primary colours to their complementary colours

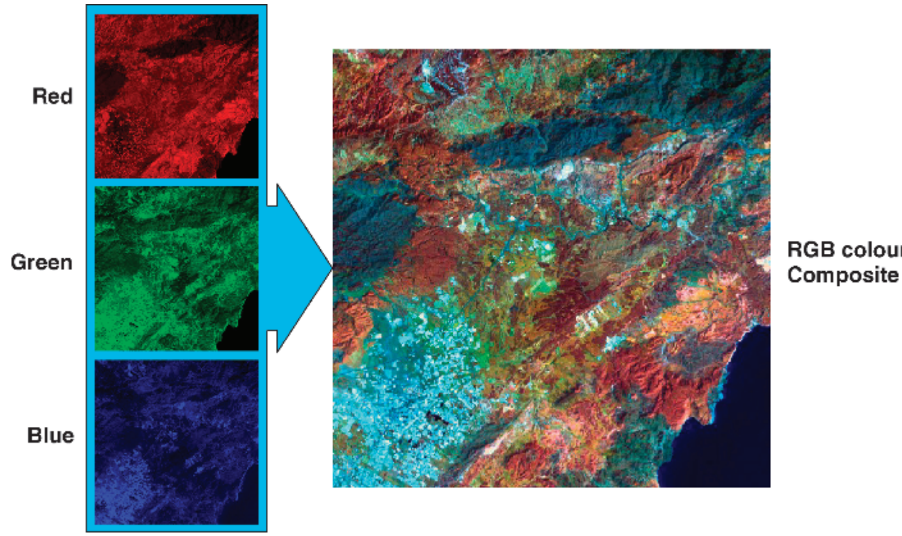


**Figure 1.3** Illustration of RGB additive colour image display

bands ($r$, $g$, $b$). For instance, if a pixel has red and green DNs of 255 and blue DN of 0, it will appears in pure yellow on display. This kind colour display system is called an *additive RGB colour composite system*. In this system, different colours are generated by additive combinations of **R**ed, **G**reen and **B**lue components.

As shown in Figure 1.4, consider the components of an RGB display as the orthogonal axes of a 3D colour space; the maximum possible DN level in each component of the display defines the *RGB colour cube*. Any image pixel in this system may be represented by a vector from the origin to somewhere within the colour cube. Most standard RGB display system can display 8 bits per pixel per channel, up to 24 bits $= 256^3$ different colours. This capacity is enough to generate a so-called 'true colour' image. 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. $r = g = b$). If the same band is used as red, green and blue components, all the pixels will lie on the grey line. In this case, a B/W image will be produced even though a colour display system is used.

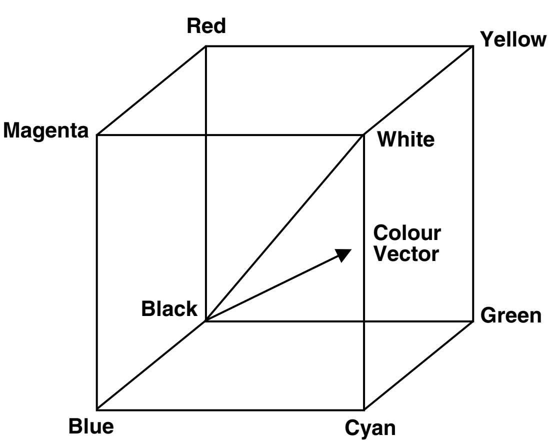


**Figure 1.4** The RGB colour cube

As mentioned before, although colours lie in the visible spectral range of 380–750 nm, they are used as a tool for information visualization in the colour display of all digital images. Thus, for digital image display, the assignment of each primary colour for a spectral band or layer can arbitrarily depend on the requirements of the application, which may not necessarily correspond to the actual colour of the spectral range of the band. If we display three image bands in the red, green and blue spectral ranges in RGB, then a *true colour composite* (TCC) image is generated (Figure 1.5, bottom left). Otherwise, if the image bands displayed in red, green and blue do not match the spectra of these three primary colours, a *false colour composite* (FCC) image is produced. A typical example is the so-called

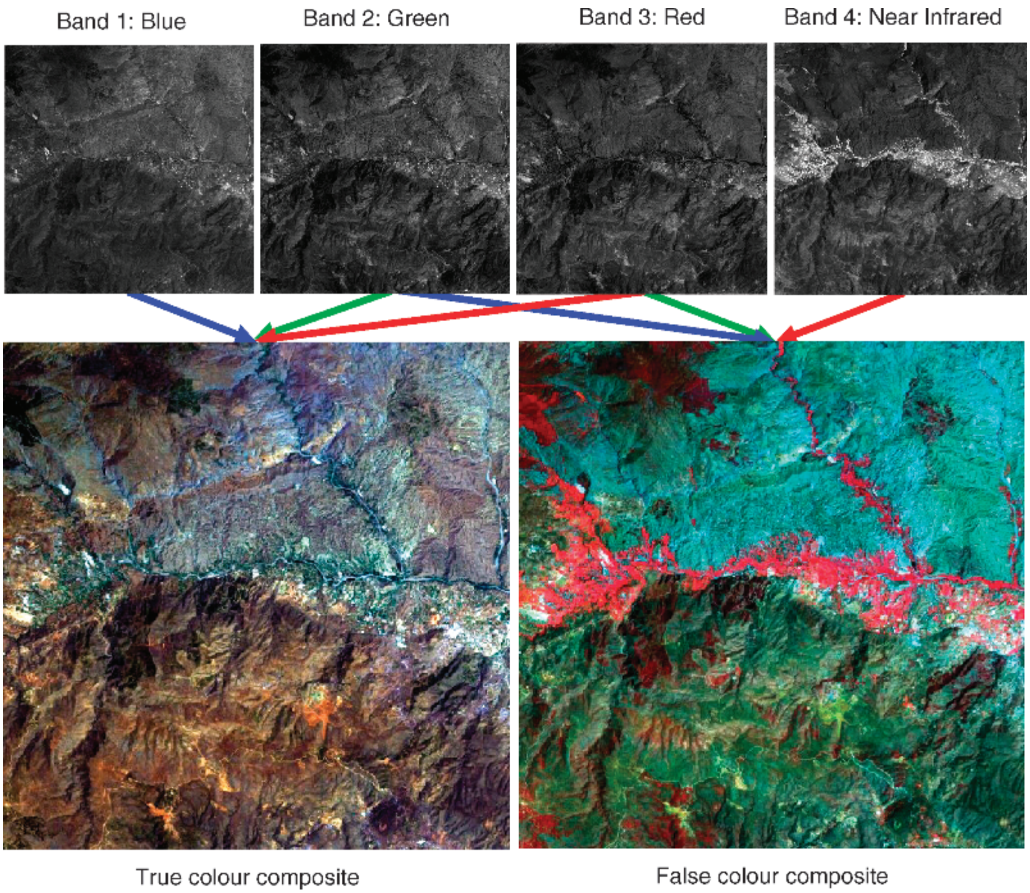


**Figure 1.5** True colour and false colour composites of blue, green, red and near-infrared bands of a Landsat-7 ETM+ image. If we display the blue band in blue, green band in green and red band in red, then a true colour composite is produced as shown at the bottom left. If we display the green band in blue, red band in green and near-infrared band in red, then a so-called standard false colour composite is produced as shown at the bottom right

*standard false colour composite* (SFCC) in which the near-infrared band is displayed in red, the red band in green and the green band in blue (Figure 1.5, bottom right). The SFCC effectively highlights any vegetation distinctively in red. Obviously, we could display various image layers, which are without any spectral relevance, as a false colour composite. The false colour composite is the general case of an RGB colour display while the true colour composite is only a special case of it.

### 1.2.3 Pseudo colour display

The human eye can recognize far more colours than it can grey levels, so colour can be used very effectively to enhance small grey-level differences in a B/W image. The technique to display a monochrome image as a colour image is called *pseudo colour display*. A pseudo colour image is generated by assigning each grey level to a unique colour (Figure 1.6). This can be done by interactive colour editing or by automatic transformation based on certain logic. A common approach is to assign a sequence of grey levels to colours of increasing spectral wavelength and intensity.

The advantage of pseudo colour display is also its disadvantage. When a digital image is displayed in grey scale, using its DNs in a monochromic display, the sequential numerical relationship between different DNs is effectively presented. This crucial information is lost in a pseudo colour display

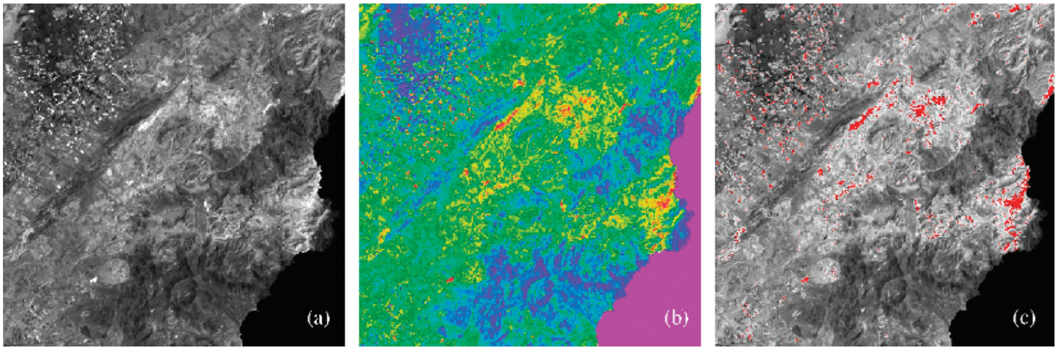


**Figure 1.6** (a) An image in grey-scale (B/W) display; (b) the same image in a pseudo colour display; and (c) the brightest DNs are highlighted in red on a grey-scale background

because the colours assigned to various grey levels are not quantitatively related in a numeric sequence. Indeed, the image in a pseudo colour display is an image of symbols; it is no longer a digital image! We can regard the grey-scale B/W display as a special case of pseudo colour display in which a sequential grey scale based on DN levels is used instead of a colour scheme. Often, we can use a combination of B/W and pseudo colour display to highlight important information in particular DN ranges in colours over a grey-scale background as shown in Figure 1.6c.

## 1.3 Some key points

In this chapter, we learnt what a digital image is and the elements comprising a digital image and we also learnt about B/W and colour displays of digital images. It is important to remember these key points:

- A digital image is a raster dataset or a 2D array of numbers.
- Our perception of colours is based on the tristimulus theory of human vision. Any colour is composed of three primary colours: red, green and blue.
- Using an RGB colour cube, a colour can be expressed as a vector of the weighted summation of red, green and blue components.
- In image processing, colours are used as a tool for image information visualization. From this viewpoint, the true colour display is a special case of the general false colour display.
- Pseudo colour display results in the loss of the numerical sequential relationship of the image DNs. It is therefore no longer a digital image; it is an image of symbols.

## Questions

1.1 What is a digital image and how is it composed?
1.2 What are the major advantages of digital images over traditional hard copy images?
1.3 Describe the tristimulus colour theory and principle of RGB additive colour composition.
1.4 Explain the relationship between primary colours and complementary colours using a diagram.
1.5 Illustrate the colour cube in a diagram. How is a colour composed of RGB components? Describe the definition of the grey line in the colour cube.
1.6 What is a false colour composite? Explain the principle of using colours as a tool to visualize spectral information of multi-spectral images.
1.7 How is a pseudo colour display generated? What are the merits and disadvantages of pseudo colour display?