1 Introduction

1.1 Digital image processing

Digital image processing is the technology of applying a number of computer algorithms to process digital images. The outcomes of this process can be either images or a set of representative characteristics or properties of the original images. The applications of digital image processing have been commonly found in robotics/intelligent systems, medical imaging, remote sensing, photography and forensics. For example, **Figure 1** illustrates a real cardiovascular ultrasonic image and its enhanced result using a Wiener filter that reduces the speckle noise for a higher signal-to-noise ratio.

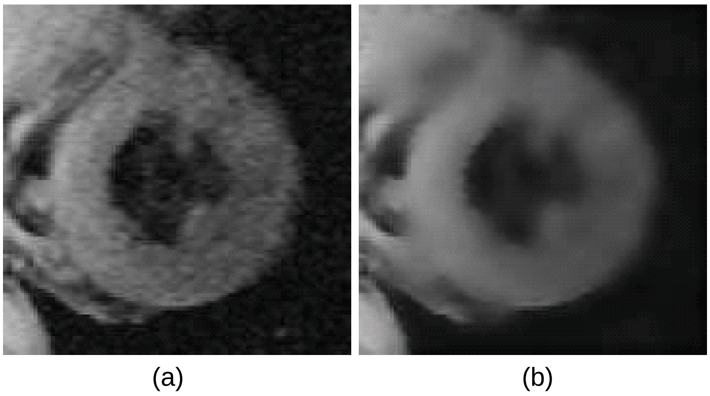

Figure 1 Illustration of image enhancement by applying a Wiener filter to a cardiovascular ultrasonic image: (a) original, (b) enhanced image.

Digital image processing directly deals with an image, which is composed of many image points. These image points, also namely *pixels*, are of spatial coordinates that indicate the position of the points in the image, and intensity (or gray level) values. A colorful image accompanies higher dimensional information than a gray image, as red, green and blue values are typically used in different combinations to reproduce colors of the image in the real world.

The RGB color model used in the color representation is based on the human perception that has attracted intensive studies with a long history. One example area of the RGB decomposition can be found in **Figure 2**. The present RGB color model is based on the Young-Helmholtz theory of trichromatic color vision, which was developed by Thomas Young and Herman Helmhotz in the early to mid nineteenth century. The Young-Helmholtz theory later led to the creation of James Clerk Maxwell's color triangle theory presented in 1860. More details on this topic can be found in [1].

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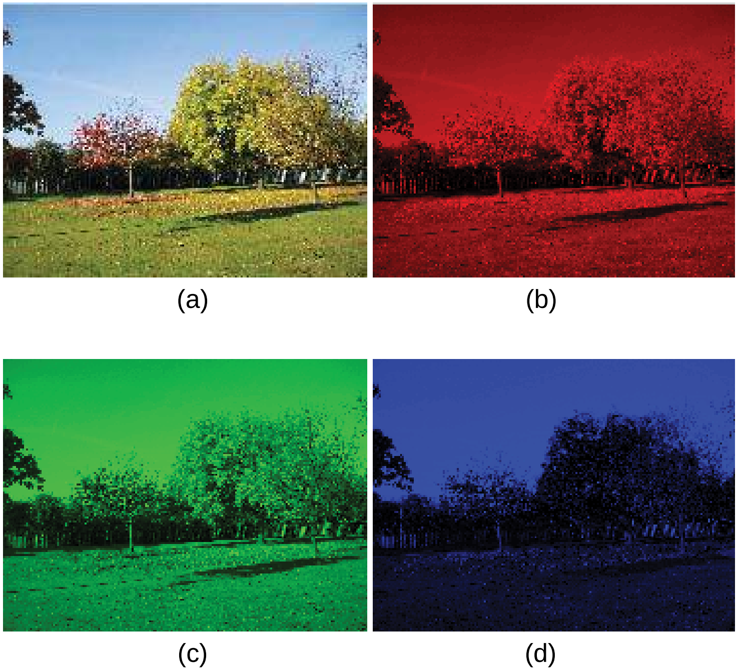

Figure 2 An RGB image along with its R, G and B components: (a) RGB image, (b) R component, (c) G component and (d) B component.

1.2 Purpose of digital image processing

The main purpose of digital image processing is to allow human beings to obtain an image of high quality or descriptive characteristics of the original image. In addition, unlike the human visual system, which is capable of adapting itself to various circumstances, imaging machines or sensors are reluctant to automatically capture "meaningful" targets. For example, these sensory systems cannot discriminate between a human subject and the background without the implementation of an intelligent algorithm.

Figure 3 denotes a successful example where a human object is separated from his background using a k-means clustering algorithm, which is part of the technologies developed in digital image processing. We use this example to justify the importance and necessity of digital image processing. To separate the human object from the background, subsequent processes will be employed. These processes can be low-, mid- and high-level. Low-level processes are related to those primitive operators such as image enhancement, and mid-level processes will get involved in image segmentation, and object classification. Finally, high-level processes are intended to find certain objects, which correspond to the pre-requisite targets [2]. The following description provides more details about the object segmentation, shown in **Figure 3**.

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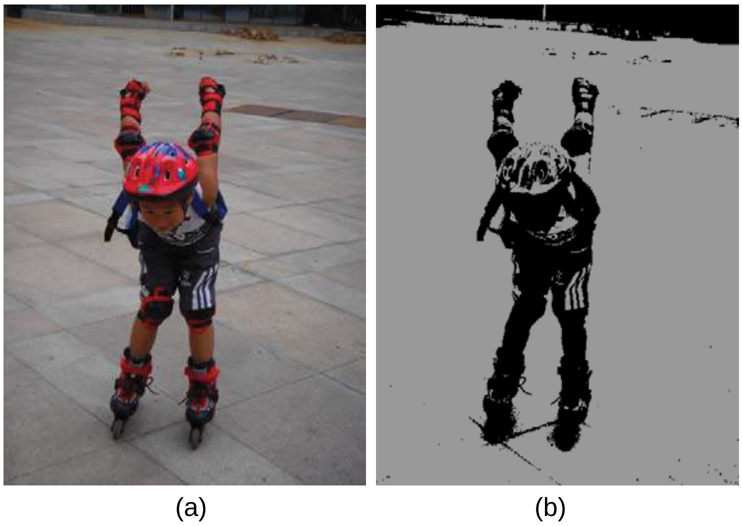

Figure 3 Illustration of human object segmentation from the background using a k-means clustering approach [5].

Low-level processes are not desirable in this particular example. This is due to the fact that the original image has been acquired in a good condition and hence no evidence of image blurring occurs. During the mid-level processes, a manual assignment of cluster centers is achieved by a professional. This leads to optimal clustering of image intensities by the automatic k-means clustering. If necessary, the extracted object will be used to generate human identity, which is one of the high-level processes. Up to now, it is clear that without digital image processing one will not be able to generate "meaningful" object in this example and beyond.

1.3 Application areas that use digital image processing

The applications of digital image processing have been tremendously wide so that it is hard to provide a comprehensive cover in this book. While being categorized according to the electromagnetism energy spectrum [2], the areas of the application of digital image processing here are summarized in relation to the service purpose. This is motivated by the fact that one particular application (e.g. surveillance) may get different sensors involved and hence presents confusing information in the categorization. In general, the fields that use digital image processing techniques can be divided into photography, remote sensing, medical imaging, forensics, transportation and military application but not limited to.

Photography: This is a process of generating pictures by using chemical or electronic sensor to record what is observed. Photography has gained popular interests from public and professionals in particular communities. For example, artists record natural or man-made objects using cameras for expressing their emotion or feelings. Scientists have used photography to study human movements (**Figure 4**).

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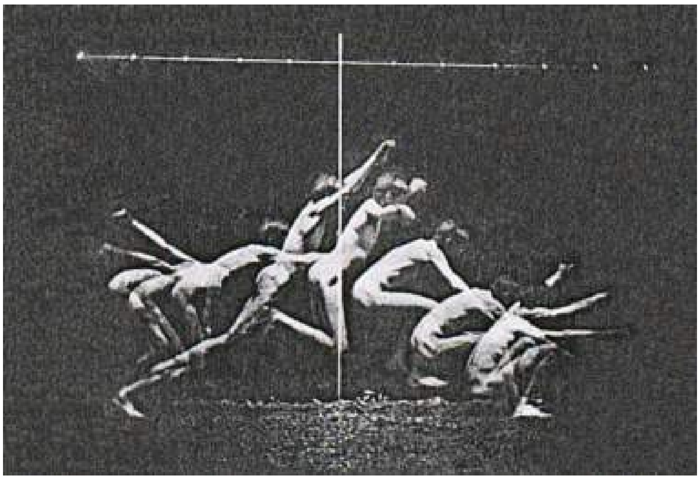

Figure 4 Study of human motion (Eakins Thomas, 1844–1916).

Remote sensing: This is a technology of employing remote sensors to gather information about the Earth. Usually the techniques used to obtain the information depend on electromagnetic radiation, force fields, or acoustic energy that can be detected by cameras, radiometers, lasers, radar systems, sonar, seismographs, thermal meters, etc.

Figure 5 illustrates a remote sensing image collected by a NASA satellite from space.

Figure 5 An example of remote sensing images (image courtesy of NASA, USA).

Medical imaging: This is a technology that can be used to generate images of a human body (or part of it). These images are then processed or analyzed by experts, who provide clinical prescription based on their observations. Ultrasonic, X-ray, Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) are quite often seen in daily life, though different sensory systems are individually applied. **Figure 6** shows some image examples of these systems.

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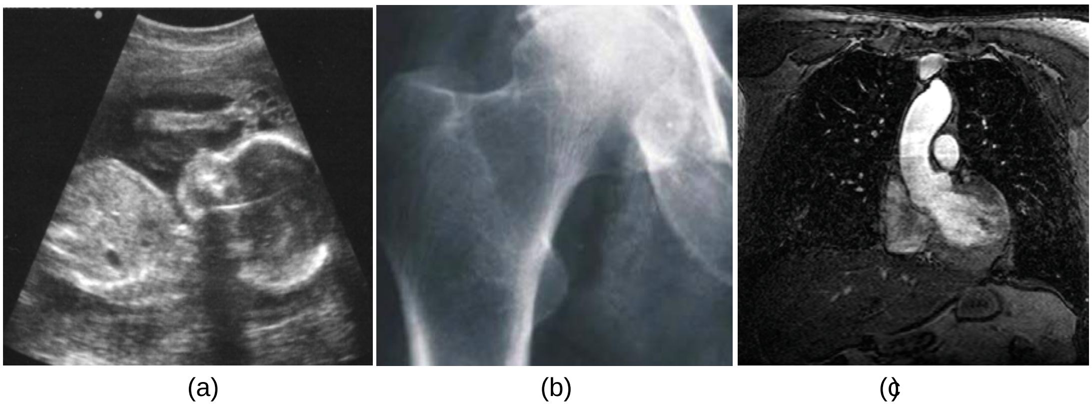

Figure 6 Medical image examples: (a) ultrasound, (b) X-ray and (c) MRI.

Forensics: This is the application of different sciences and technologies in the interests of legal systems. The purpose of digital image processing in this field is used to be against criminals or malicious activities. For example, suspicious fingerprints are commonly compared to the templates stored in the databases (see **Figure 7**). On the other hand, DNA residuals left behind by the criminals can be corresponding to their counterparts saved in the DNA banks.

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Figure 7 A fingerprint image.

Transportation: This is a new area that has just been developed in recent years. One of the key technological progresses is the design of automatically driven vehicles, where imaging systems play a vital role in path planning, obstacle avoidance and servo control. Digital image processing has also found its applications in traffic control and transportation planning, etc.

Military: This area has been overwhelmingly studied recently. Existing applications consist of object detection, tracking and three dimensional reconstructions of territory, etc. For example, a human body or any subject producing heat can be detected in night time using infrared imaging sensors (**Figure 8**). This technique has been commonly used in the battle fields. Another example is that three dimensional recovery of a target is used to find its correspondence to the template stored in the database before this target is destroyed by a missile.

Figure 8 An infrared image of tanks (image courtesy of Michigan Technological University, USA).

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1.4 Components of an image processing system

An image processing system can consist of a light source that illuminates the scene, a sensor system (e.g. CCD camera), a frame grabber that can be used to collect images and a computer that stores necessary software packages to process the collected images. Some I/O interfaces, the computer screen and output devices (e.g. printers) can be included as well. **Figure 9** denotes an image processing system.

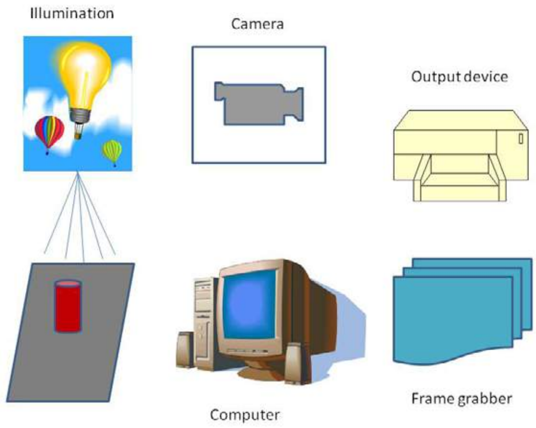

Figure 9 Components of an image processing system.

1.5 Visual perception

Digital image processing is performed in order that an image does fit the human visual judgments. Before our study goes further, the human visual system has to be studied so that the target of image processing can be properly defined. In this subsection, we briefly describe the vision principle of the human eye.

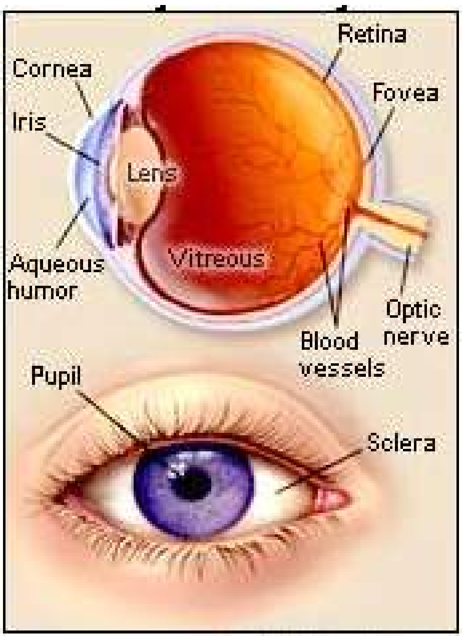

Figure 10 Illustration of eye anatomy (image courtesy of [3]).

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The reflected light from the object enters the external layer that coats the front of the eye, which is called the cornea (see **Figure 10**). Afterwards, the light passes through some watery fluid namely the aqueous humor. Then the light reaches the iris that may contract or dilate so as to limit or increase the amount of light that strikes the eye. Passing through the iris, the light now arrives at the pupil, a black dot in the centre of the eye, and then reaches the lens. The lens can change its shape in order to obtain focus on reflected light from the nearer or further objects.

1.6 Image acquisition

Images are generated from the combination of an illuminant source and the reflection of energy from the source. In general, images can be two dimensional (2-D) or three-dimensional (3-D), depending on the used sensors and methodologies. For example, a set of 2-D cardiovascular images can be piled up to form a 3-D image using an automatic correspondence algorithm. These 3-D reconstruction techniques will be detailed in later chapters.

Image acquisition can be categorized to single sensor, sensor strips, and sensor arrays based. For example, a photodiode is made of a single sensor (see **Figure 11**). Computerized tomography uses sensor strips to measure the absorption of x-ray that penetrates the human body. **Figure 12** shows one of these systems. An ordinary camera (e.g. Olympus E-620) is based on rugged arrays that normally consist of millions elements.

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Figure 11 Illustration of a photodiode.

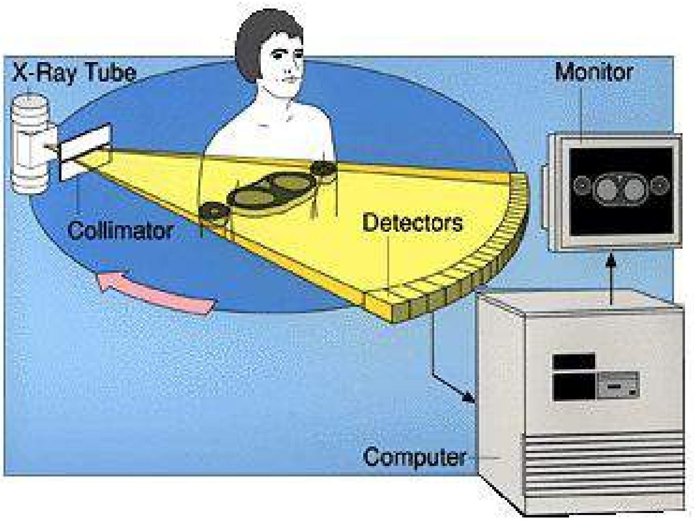

Figure 12 Illustration of a computerized tomography system (image courtesy of [4]).

1.7 Image sampling and quantization

1.7.1 Basic concepts in sampling and quantization

An image consists of an indefinite number of points with continuous coordinates and amplitudes. To convert this image to digital form, both the image coordinates and amplitudes must be discretized, where the image points will be changed to pixels while the amplitudes use discrete values. Sampling refers to digitization of the coordinates, and quantization is the digitization of the amplitude values.

Figure 13 shows an example of image sampling and quantization, where (b) reveals that the image resolution is reduced, whilst (c) indicates that gray levels decrease, compared to (a).

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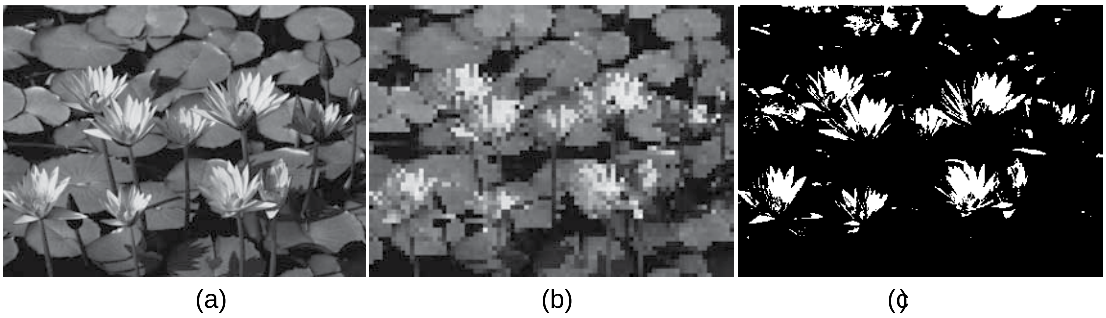

Figure 13 Illustration of image sampling and quantization: (a) original, (b) sampling and (c) quantization.

1.7.2 Representing digital images

An image is normally represented in matrix form, originating from the upper left corner. Also, an image consists of a certain number of gray levels. For example, if it has 2^m gray levels, this image is referred to "m-bit image". One of the regular manipulations on the image is zooming or shrinking. Either way may bring down the resolutions of the original image due to interpolation or extrapolation of image points.

One of the commonly noticed image problem is aliasing. This phenomenon appears when the interval of image sampling is higher than a half of the distance between two neighboring images points. As a result, the Moiré pattern effect will appear and seriously deteriorate the image quality.

1.8 Basic relationship between pixels

1.8.1 Neighbors of a pixel

Assuming that a pixel has the coordinates (x, y), we then have its horizontal and vertical neighbors which have coordinates as follows

$$(x+1, y), (x-1, y), (x, y+1) \text{ and } (x, y-1) \tag{1.8.1}$$

We can have four diagonal neighbors of the point (x, y) below

$$(x+1, y+1), (x+1, y-1), (x-1, y+1) \text{ and } (x-1, y-1) \tag{1.8.2}$$

1.8.2 Adjacency, connectivity, regions, and boundaries

If an image point falls in the neighborhood of one particular pixel, we then call this image point as the adjacency of that pixel. Normally, there are two types of adjacency, namely 4- and 8-adjacency:

1) 4-adjacency: Two pixels are 4-adjacent if one of them is in the set with four pixels.
2) 8-adjacency: Two pixels are 8-adjacent if one of them is in the set with eight pixels. One example is shown below, where red "1s" form the 8-adjacency set.

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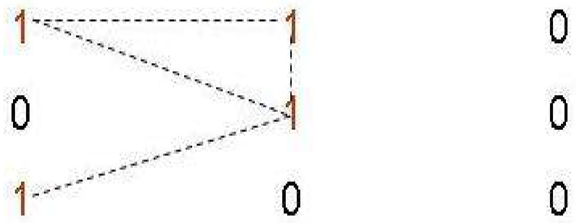

Connectivity is relevant but has certain difference from adjacency. Two pixels from a subset G are connected if and only if a path linking them also connects all the pixels within G. In addition, G is a region of the image as it is a connected subset. A boundary is a group of pixels that have one or more neighbors that do not belong to the group.

1.8.3 Distance measures

Assuming there are two image points with coordinates (x, y) and (u, v). A distance measure is normally conducted for evaluating how close these two pixels are and how they are related. A number of distance measurements have been commonly used for this purpose, e.g. Euclidean distance. Examples of them will be introduced as follows.

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The Euclidean distance between two 2-D points $I(x_1,y_1)$ and $J(x_2,y_2)$ is defined as:

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{1.8.3}$$

The City-block distance between two 2-D points (x_1,y_1) and (x_2, y_2) can be calculated as follows:

$$| x_1 - x_2 | + | y_1 - y_2 | \tag{1.8.4}$$

For the above two 2-D image points, the Chessboard distance is

$$\max(| x_1 - x_2 |, | y_1 - y_2 |) \tag{1.8.5}$$

1.9 Summary

In this chapter, basic concepts and principles of digital image processing have been introduced. In general, this chapter started from the introduction of digital image processing, followed by a summary of different applications of digital image processing. Afterwards, the fundamental components of an image processing systems were presented. In addition, some commonly used techniques have been summarized.

In spite of their incomplete stories and terse descriptions, these presented contents are representative and descriptive. The knowledge underlying with this introduction will be used in later chapters for better understanding of advanced technologies developed in this field.

1.10 References

[1] http://en.wikipedia.org/wiki/RGB, accessed on 29 September, 2009.
[2] R.C. Gonzalez and R.E. Woods, Digital Image Processing, 2nd version, Prentice-Hall, Inc. New Jersey, 2002.
[3] http://www.webmd.com/eye-health/amazing-human-eye, accessed on 29 September, 2009.
[4] http://www.imaginis.com/ct-scan/how_ct.asp, accessed on 29 September, 2009.
[5] http://en.wikipedia.org/wiki/K-means_algorithm, accessed on 29 September, 2009.

1.11 Problems

(1) What is digital image processing?
(2) Why do we need digital image processing?
(3) Please summarize the applications of digital image processing in the society.
(4) How is the human visual perception formed?
(5) What is the difference between image sampling and quantization?
(6) What is the difference between adjacency and connectivity?
(7) How to compute the Euclidean distance between two pixels?

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