IMAGE PROCESSING

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Summary

Image processing, or more specifically digital image processing is one of the many important specialist areas of computing. It is an enabling technology for a wide range of applications including remote sensing, security, image databases, digital television and robotics. This chapter reviews the hierarchical four level structure of image processing techniques. Pre-processing techniques are designed to remove distortions introduced by sensors. Low level image processing techniques are mathematical or logical operators that perform simple processing tasks. Medium level image processing combines the simple low level operators to perform feature extraction and pattern recognition functions. High level image processing uses combinations of medium level functions to perform interpretation. Since this last level is effectively modeling the human visual response, the chapter briefly notes features of vision and perception. It also highlights two key image processing actions. Interpolation is a fundamental geometric operation used, for example, to map images to geographical coordinates. Edge detection is an operation that can be simple or, as when at the heart of many recognition tasks, quite

complex. It serves as an excellent illustration of the distinctions in the image processing hierarchy. The chapter concludes with a brief examination of some of the key application areas and some commonly available image processing packages.

1. Introduction

In the early 19th century, the development of photography provided a mechanical means of capturing what the human eye could see. Individuals could now record their likeness and, instead of reading about far away places, see a detailed representation of them. By the late 19th century, photography was both a popular pastime and an integral part of newspapers, books, journals and magazines. Then came the 'moving picture' and by the 1920s, a major new entertainment medium. In the 1930s, color photography was developed and the first television service began in Britain. World War II saw the rise of radar, with the location of detected objects being displayed as an electronic image. The first color television service began in the United States in January 1954 and also about that time the broadcast videotape recorder was created. These developments had related scientific and industrial outgrowths such as photographic film to record X rays or infrared radiation. Some innovative image capture systems were also created such as Schlieren photography. Originally developed to detect flaws in glass, it is probably best recognized now for showing the shock waves or turbulence about aircraft wings.

In spite of the increasing sophistication of the technology, in a strict technical sense all that had been developed until the 1950s was systems for image capture and storage. No system existed where, for example, images taken of microscope slides could be automatically processed to detect cancer cells.

The development of the laser in the 1950s provided a means of achieving that. The coherency of laser light allows a system to be set up to detect particular objects within photographs as well as other processing actions. As these systems require an optical bench with precision optical components such as lenses, gratings and filters, the number of applications for this approach has been limited. One of the first was processing the output of synthetic aperture radars (SARs), or sideways radars, used in remotely sensing terrain for exploration and mapping.

The early space probes could sense the physical properties of the planets, but the natural human inclination was to view them. Thus image sensors were installed, the captured images were digitized, compressed to reduce the data volume and then encoded so they could be communicated accurately bit by bit back to earth over the very long distances involved. On reception, the data was passed to a computer to check the coding and decompress the image. The sensors, though, distorted the images in various ways, particularly geometrically. Given a computer can perform a complex sequence of mathematical operations on any input; then it was natural to program the computer to correct this distortion.

This describes a system where an image is an input to a processing system. Thus image processing as we now largely know it began. That is to say, digital image processing. The cost of computing in the 1970s limited the field, but as that cost fell in successive decades, the impact of digital image processing began to rise significantly. Now, almost all images routinely seen in newspapers, books, advertising displays, magazines, journals and on television have been processed to some extent digitally. Further, computing has now reached a point where any user of a personal computer can acquire a range of software products at a reasonable price to undertake quite sophisticated image processing of almost any form. Very often, this is on images captured by that user's own digital camera.

Image processing may be categorized in several ways. In terms of the means by which it is implemented, there is analog and digital image processing, but here only the latter will be considered. In terms of the broad focus, it may be described as analytic or synthetic. Synthesizing (digital) images is part of computer graphics and will also not be considered. Nevertheless, it is important to mention that the boundaries between analysis and synthesis can be blurred. For example, many special effects in film, television and advertising include elements of analysis as well as synthesis. To illustrate, in the Lord of the Rings films, scenes were needed of a dark environment with an active volcano. To achieve it, film was shot of an extinct volcano in New Zealand, it was processed to give the environment and the eruption was synthesized. Some modern areas of medical image processing such as virtual surgery also combine elements of analysis and synthesis.

In terms of the focus of analysis, image processing may be described as objective or subjective. Objective focuses on the functional. For example, it may be to detect particular objects within the image or to transform it in a particular way such as by removing noise or generating false colors. The outcome of processing, therefore, can be an image but it may also be more mundane such as a description of the number of each particular object identified and their properties. Subjective means the focus is essentially aesthetic; to manipulate the image in some way to improve its appeal to a human viewer. Here, the outcome is always an image. The steps leading to it, though, will involve objective actions such as filtering.

2. Some Comments on Vision

Vision is one of the most important senses for living creatures for two main reasons:

- *Perception*
  There is a need for them to identify objects and their location within their surroundings and so understand the environment in which they find themselves. This may be a very special ability as with insects, or an extremely sophisticated capability as with humans.

- *Guidance*
  Sighted creatures have the ability to avoid collision with - or capture by - objects in their surroundings. They may also plan movements in their surroundings. For many too, there is a need to be able to position particular body parts in relation to each other and to locations within the surroundings. For example, with humans to see how their hands are positioned to pick up an object.

This suggests there may be an advantage to examining biological vision from two viewpoints:

- *Spatial vision*
  The process for deriving information on spatial relationships.

- *Temporal vision*
  The process for deriving information on changes within an environment over time.

In general, references to vision mean studies of the human visual response. Specifically, vision refers to the study of the physical processes involved in that response and so is focused on the eye. Visual perception refers to the study of the functional behavior of the physical and cognitive responses and studies the eye as well as the visual cortex within the brain. As a system, the human visual response accepts a stereoscopic image in general and as an output provides information to guide the behavior of a human.

There are many reasons why visual response should be studied. One is so that machine vision systems can be easily created; that is to say, a system that mimics all or part of the human visual response, or for that matter the visual response of another creature. With this base, though, response systems can be created with expanded capabilities. In particular, perceptive functions not part of human or animal vision. If that is the case, then any definition of images and image processing needs to be sufficiently broad to encompass all such possibilities.

There are many aspects of visual response that are of importance to psychology but rarely faced in the digital image processing literature. For example, when is an image perceived as being ‘natural’ and when as synthesized? Much more complex; how to measure the aesthetic qualities of an image? This is in fact a question of some significance in digital image processing as it would suggest means of improving the subjective quality. However, it is such a complex issue that in general the approach is simply to provide tools to a human operator and leave the issue to their judgment.

3. What Is An Image?

The traditional view of an image derives heavily from experience in photography, television and the like. In the abstract, this view sees an image in these terms:

- It is a two dimensional structure.
- It is a representation.
- It is a structure with meaning to a visual response system.

While there are many implications of these terms, at this juncture it is useful to highlight just two. This definition assumes an image exists, but that in turn assumes a process of image formation. Such a process may influence an understanding of what is an image. There is also an implication in this definition of purpose. That is to say, the image exists so that it may be subject to some form of interpretative action.

This view of an image only accepts spatial variation. In modern parlance, this would be described as a static image. However, there are a number of potential applications where other forms of variation need to be considered. In accommodating those, the concept of an image needs to shift a little to encompass a view of a sample or section - a window - of a more complex structure. In particular:

- A dynamic image has spatial and temporal variation. In most contexts, this is usually referred to as video. In most cases this more complex structure needs to be viewed - if digital - as a sequence of images each representing a particular instance in time.

- Consider a volume. Then an image can be formed by taking a sampling plane through that volume and so the variation in three dimensions observed. This may be referred to as a volume image.

An image linked to a volume that changes with time is a further possibility. This has significance in medical image processing applications and some other areas.

4. The Relationship between Digital and Analog Images

It is easy to become confused about the meaning of analog and digital with respect to images as there are many examples that seem to be neither one nor the other. A transducer is a device that converts some form of energy to an electrical signal. Here, the magnitude of the output directly relates to the strength of the input and the term analog was adopted to describe this. In time, though, analog came to mean any continuous signal. In a modern context, it is also used in the sense of being not digital.

To transform an analog into a digital image involves three conceptual stages:

- *Sampling*
  A two dimensional grid is formed over the continuous analog image. Then the radiometric value is measured at the intersection points of this grid.

- *Quantization*
  Each of the samples is restricted so that it can only take a finite set of values.

- *Coding*
  These finite values or pixels (for picture elements) are now expressed by a binary number. Thus a digital signal is formed as a sequence of binary numbers.

The process is illustrated with a one dimensional example:

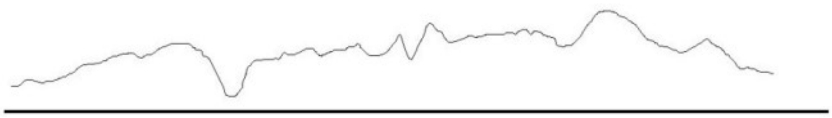

Figure 1a: A one dimensional analog signal

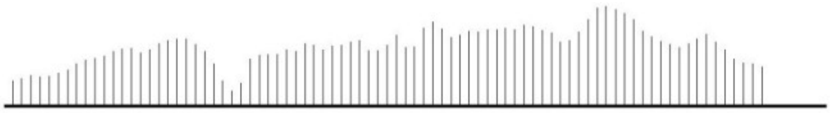

Figure 1b: The sampled analog signal

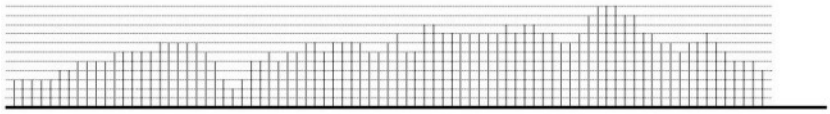

Figure 1c: The quantized sampled signal

The coding follows from the quantized levels.

Although the output is regarded as numbers, they would normally be communicated by a train of pulses. However, whereas in analog systems the shape of the pulse would be important and needs to be preserved, in a digital signal the issue is only whether what is present should be classed as a pulse or not. This illustrates a key reason for digitizing; it gives a result impervious to the usual sources of electrical noise so allowing perfect reproduction of an original.

Nyquist's sampling theorem is a famous result that states a digital signal is equivalent to the analog from which it was derived if the sampling rate is at least twice the bandwidth of the analog signal. Equivalence means it is possible to perfectly recover the analog signal from the digital by a process of ideal low pass filtering. Hence in practice it is usually considered sampling needs to be 20% higher than the Nyquist rate so that recovery is possible with a practical low pass filter. If sampling occurs below the Nyquist rate, then any recovered analog signal will have an interference pattern termed aliasing. For this reason, it is important to filter an analog signal so that when digitized it is known to meet Nyquist's criterion.

For images, aliasing can occur if the spatial sampling rate is not twice the spatial frequency response. That aliasing can take several forms. A very well-known one is 'jaggies' where straight lines are represented by closely linked segments.

This is a particular difficulty in computer graphics where regular geometric objects feature. In other images, a particular problem caused by aliasing is that it may lead to artifacts that can be interpreted as features of the image. This is a particular danger, of course, in medical image processing. Again, this problem can be overcome by filtering, in this case spatial filtering, the image prior to sampling. In visual terms, this is equivalent to blurring.

A discrete signal is not digital. The difference between the two is caused by the quantization process and it is an irreversible impairment. The impact of this is that the digital signal may be regarded as a noisy version of the discrete and so the original analog signal. The signal to quantization noise ratio is a widely quoted figure of merit and it is given by:

Signal to Noise ratio = $6.02N + 10.79$ dB

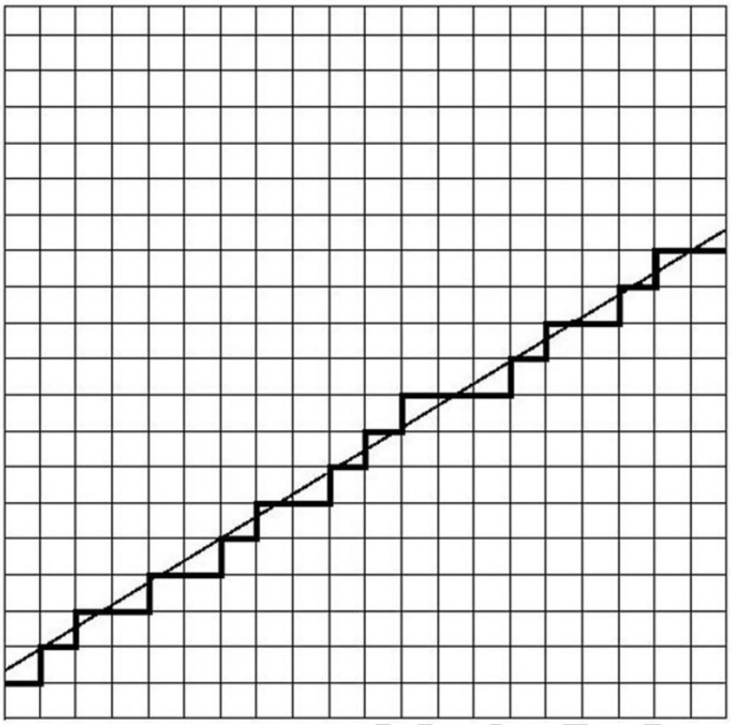

Figure 2: An illustration of aliasing; 'jaggies' on a line.

where N is the number of bits of the quantized word. Tests can establish the minimum acceptable signal to quantization noise for different signals. Quantization noise, though, is not random and for that reason care needs to be exercised when examining any signal to quantization noise ratio. For common images, if the signal to quantization ratio exceeds 50 dB, then the human eye can rarely detect any perturbation which suggests that quantizing luminance to 8 bits is more than adequate. However, this is not true of all forms of images. For X ray images, for example, the far greater contrast ratio provided generally argues for quantization to 16 bits.

If the imagery is video there is a further issue to consider, namely aliasing effects due to temporal quantization. This leads to motion irregularities. An illustration can be seen in old western films during the inevitable chase. As the wagons increase in speed, the wheels appear to rotate faster, but then a point is reached where they slow, stop and then rotate in the other direction. This quantization effect is due to the video being a sequence of images and so, in the time domain, being discrete.

A static digital image, then, is a quite complex data structure with a range of geometric and radiometric attributes:

- *Geometric*
  There is a finite spatial extent in each dimension defined by the size of the sampling grid in the image space. That is to say, the image is N pixels wide by M pixels high. This is sometimes termed the image resolution.

  There is a spatial resolution in each dimension. That is, the spacing between sampling points in the grid. This can be uniform or non-uniform, but the former is more common. To illustrate, many common printers have a spatial resolution of 300 dots per inch (dpi).

There may also be an orientation of the grid with respect to some reference system that needs to be considered.

- *Radiometric*
  There may be a single radiometric value, a triple of radiometric values representing red, green and blue primaries or many radiometric values representing a range of spectral bands. Each will have some radiometric resolution dependent on the quantization. In the case of a color triple, the representation may be RGB, but it can also be YHS (luminance, hue, saturation) or luminance with some particular set of chrominance coordinates.

  There will be a contrast ratio set by whatever the smallest and largest pixel values represent for each radiometric value.

  Depending, of course, on the type of the image, there may be some relationship – usually a power law – describing how pixel magnitudes map into brightness values. If it is a power law, then only the power needs to be known and this is described as the gamma.

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The computer vision home page found at: http://www-2.cs.cmu.edu/~cil/vision.html [This page has an extensive range of resources devoted to all aspects of image processing covering both researchers and practitioners.]

The University of Southern California's Signal and Image Processing Institute maintains an archive of the standard images used in image processing publications. It is found at http://sipi.usc.edu/services.html

Two web sites worth visiting are:

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Biographical Sketch

Dr. Myers graduated from the University of Western Australia with a B.E. degree in communications engineering in1969 and an M.Eng.Sc degree in control systems engineering in 1971. He then worked for the Weapons Assessment Unit of the Department of the Navy investigating various combat systems. He later joined the Western Australian Institute of Technology where in 1987 this became Curtin University of Technology. In 1982 he completed a Ph.D at the University of Western Australia on image processing, presenting a thesis on filtering techniques derived from observations of the human visual response. About that time, he was strongly involved in the development of one of the first NOAA satellite receiving stations in the world. This later resulted in the formation of WASTAC, a remote sensing consortium involving Curtin and government agencies with a charter to collect satellite data. WASTAC now runs receiving facilities for several satellites and plays a pivotal role in Australian remote sensing. A first application of this work in remote sensing was a major study of how satellite data could be used to assist the fishing industry. Later, he was principal investigator of a study into the recognition of Australian wheat varieties through image processing techniques. More recently, he assisted in the formation and development of multimedia group under the Australian Government's Cooperative Multimedia Centre scheme. Dr Myers has published a book on digital signal processing and contributed chapters to books on image processing and remote sensing. He has published a number of papers on the applications of image processing, especially in remote sensing and agricultural applications.