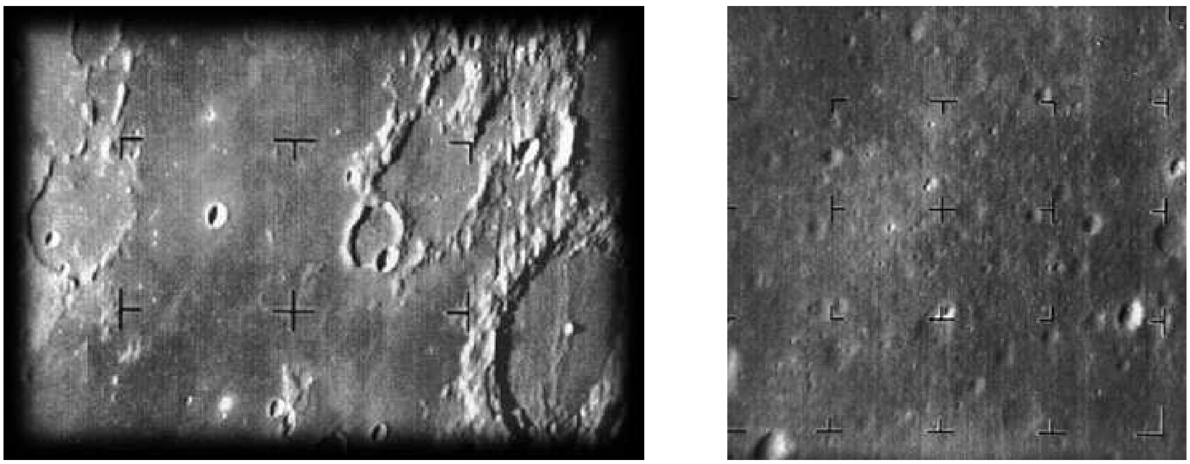
Topic 1: Introduction

1.1 Historical Background

The very earliest attempts at digital encoding and transmission of images goes back to about 1920 where the images were encoded as a series of typable characters sent via telegraph systems. These early results were essentially transmission of half-tone images, and did not constitute *Digital Image Processing*. True *Digital Image Processing* was first introduced about 1960 at the Jet Propulsion Laboratories, Pasadena, and was first used in the geometrical correction of RANGER-7 video images of the moon received in 1964. These images were severely distorted by geometric aberrations in the video system and transmission errors, with typical images in figure 1.



(a) (b)

Figure 1: Images from the Ranger-7 space mission, (a) first image from Ranger-7 (b) the *last* image send 2.5 second before impact with the moon's surface, from www.nasa,gov

This early software was then developed and used extensively for the Surveyor and Mariner space mission images, with a typical image from the MARINER missions showing the surface of Mercury in figure 2 Most of the early work on digital images were related to the space programme, with particular efforts in the geometric correction of imaging systems, transmission errors (giving the characteristic snow from data drop-outs), and non-linear sensor responses giving the characteristic image striping. All this early work was oriented towards the improved visual display of the images, with little or no work related to the automated interpretation and analysis of images by computer. In the late sixties and early seventies there were very few centres working on image processing due to the vast hardware costs involved, particularly in relation to the required large scale computer systems and image input, display, and output devices. (It should be noted that a 32 kbyte machine was a major computing resource in 1965). This initially kept *Digital Image Processing* in the domain of the expensive research projects, ie. space missions, satellite imaging and astronomical images.

From the late seventies onwards, the spread of relatively cheap SUPER-MINI computers has lead to very rapid development of Digital Image Processing, These machines, such as the VAX 11/780, with typical machine shown in figure 3, DATA GENERAL VM8000, etc., were large enough to support viable image processing, and cheap enough to be purchased on fairly

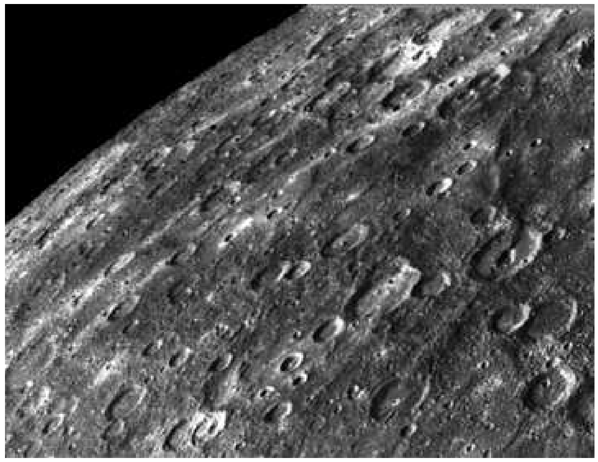


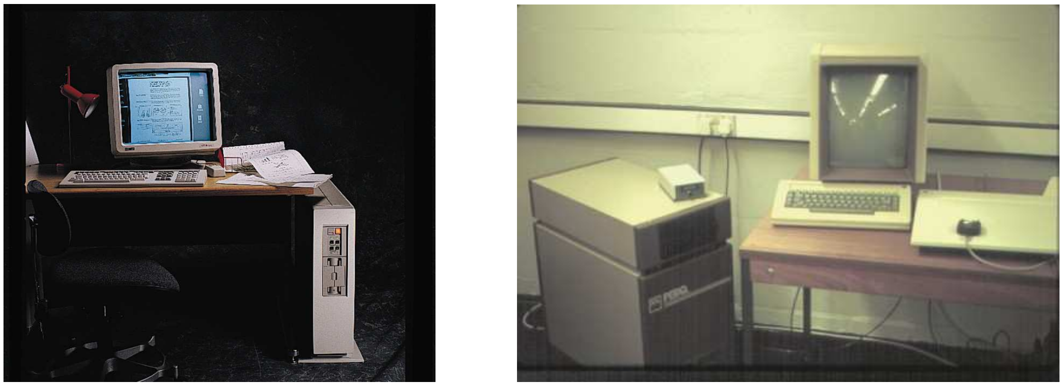
Figure 2: Image from the Mercury MARINER mission, (1074), www.nasa,gov

modest research projects. In the UK the main push was the STARLINK project which was also the start of the JANET inter-university network, the precursor to the INTERNET.

Figure 3: A typical VAX 11/780 from about 1980.

This spread of *Digital Image Processing* was further boosted in the mid 1980s the introduction of the *Graphics Workstation*, (Sun-3 VaxStation, Apollo Domain etc.), which used micro-processor technology giving significant processor power, comparable the the SUPER-MINIS combined with and high quality graphics for image display, all is a desk-side package as cost accessible to a single researcher. The typical examples are shown in figure 4, being the VAXSTATION and the PERQ, the latter was actually made in the UK! It was during this period that image processing moved out of the big space-science laboratory and started being used for industrial inspection, scientific imaging and the start of computer vision. This was the main growth area with many of the most important textbook coming from this era.

During the late 1980s and early 1990, these early graphics workstations became faster and cheaper with, by 1990, a range of hi-spec *Supercomputer* graphics workstations, (SUN 10/40, HP-9000, DEC-ALPHA, SILICON-GRAPHICS), which offered viable processor power, with by them 100-MIPS common, Ether-net connections to central servers, and X-WINDOWS graphical environment, with two typical system show in figure 5 (a)-(b). Also at this time a whole range of very expensive graphics engines were developed, with a typical large SILICON GRAPHICS, INFINITY-REALITY engine shown in figure 5 (c). These system started the ideal of *real-time*



(a) (a)

Figure 4: (a) The VaxStation and (b) the Perq, both from about 1983 which give significant processor power and quality graphics display.

image processing with video input via special hardware. These system were too expensive to make image processing common place, but moved the applications forward in medical imaging, scientific and microscope imaging and particularly in graphics and animation.

(a) (b) (c)

Figure 5: (a) The Dec-Alpha workstation, (b) the Silicon Graphics O_2 and (c) the Silicon Graphics Infinity-Reality graphics engine, all from about 1990.

From about 2000 onwards the PC *comes of age*, with a very average Pentium powered system offering the sort of computational and graphical performance only previously available in hi-spec Supercomputer graphics workstations, but as a fraction of the cost. This, combined with the development of digital photography, moved digital imaging and digital image processing into the *mass-market*, with many of the complex packages becoming available on even laptops. In this period image processing has become routine in scientific circles, and rapidly spreading though the mass consumer market.

From about 2003 onwards, digital imaging has gone *mass market* with digital camera in mobile telephones and PDA, if fact it is now difficult to find a non-digital camera. All PC are now sold with a *digital manipulation package* which implements many of the standard image processing tasks such as colour balancing, cropping, resizing and even elementary image enhancement such as edge sharpening. The big growth is in digital video, which due to the huge inherent data rates, requires data compression and hence built-in image processing.

All image processing, whether for scientific remote sensing of the Earth or enhancement of the *party snaps* to remove *red-eye* is all based on the same concepts of holding and processing images as two-dimensional array of numbers. There is the same underlying mathematical and physical models, and, in most cases, use exactly the same processing techniques. It is these models and techniques that we will be considering in this course.

1.2 Digital Image Processing Tasks

The field of image processing can be broken into a series of application based tasks, which can be thought of as fairly well separated; these being:

Image Reconstruction

In these applications the collected image is aberrated, (perhaps blurred), by either properties of the image collection system, or environment. The aim is then to restore or reconstruct the best image from the collected data. These techniques vary from simple display operations, such as contrast enhancement, to very sophisticated model and statistical based reconstruction techniques, as shown in figure 6 which is an example of using a MAXIMUM ENTROPY scheme to reconstruct a blurred image. The final *output* image may either be for visual display or then passed on to a automated vision system.

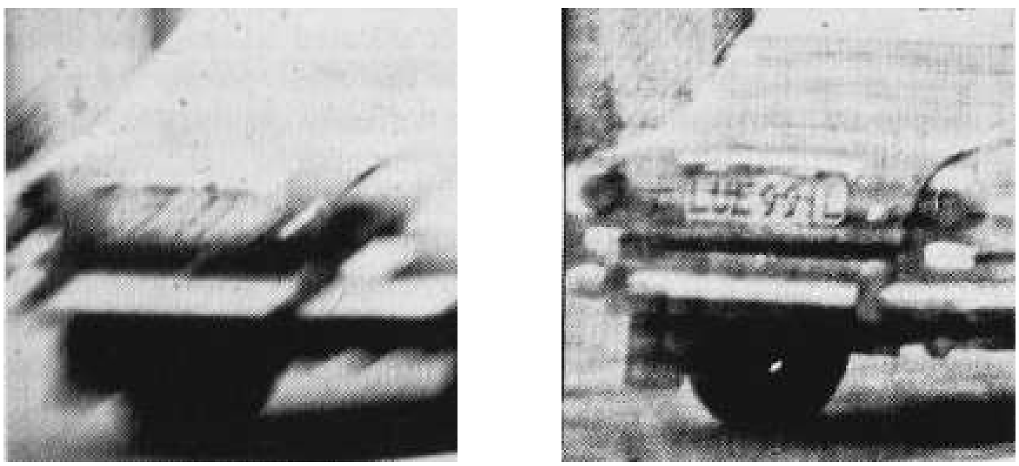


Figure 6: Example of maximum entropy to reconstruct a blurred images.

Image Analysis, Pattern Recognition and Computer Vision

This is typically involved with object detection and recognition by computer of simple known objects. The images are extensively processed, typically to obtain edges of other parametric measures such as shape primitives, for example detection of lines in figure 7 using the Hough transform. The aim of these systems is to attach a *label* or sequence of *labels* to an image. In this case the *processed image*.

Figure 7: Extraction of linear features, roads in this case, from a satellite image using edge detection followed by analysis using Hough transforms.

Image Formation by Computer

In certain imaging techniques such as *Computer Tomography* and *Aperture Synthesis*, the collected data has to be extensively processed by computer in order to form the image, frequently employing many of the techniques of image reconstruction. Three examples are shown in figure 8. In addition, the techniques of image synthesis used in molecular graphics, shape modelling for Computer Aided Design (CAD), and recently scene modelling for advertising and video effects use the basic techniques of image processing and display.

(a) (b) (c)

Figure 8: Range of images formed by computer, (a) three-dimensional model of a skull formed from computer tomography, (b) image of a spiral galaxy formed by aperture synthesis to enhance resolution, (c) a synthetic radar satellite image.

Image Compression and Encoding

With the huge growth of digital imaging, and especially digital video, image compression and encoding has become a huge part of digital image processing. With images the compression task is very different to conventional computer compression, such as ZIP, since for images the reconstruction may be *lossy*, but if it contains sufficient information may be useful for the required task. This allow for potentially huge compressions, often 1:100 being possible. The most common, and most practical is JPEG, shown below in figure 9, which involves encoding of blocks of the image using the cosine transform, being closely related to the Fourier transform.

Figure 9: Example of JPEG compression.

1.3 Applications of Digital Image Processing

The following list contains a summary of applications of Digital Image Processing.

- **Remote Sensing:** Interpretation and classification of satellite data for crop monitoring, earth resource survey, weather forecasting and map production. This involves large scale image processing of multi-spectral data received from satellites in earths orbit.
- **Inspection and Automation:** Range of pattern recognition and computer vision system is automated control, robotic assemble, quality control and safety monitoring.
- **Medical Imaging:** Image formation in computer tomography, magnetic resonance imaging (MRI), gamma-camera, ultra-sound tomography and positron emission tomography (PET). Image reconstruction and enhancement for x-ray images, and ultra-sound images.
- **Astronomical Applications:** Image enhancement and restoration of optical images, removal of imaging artifacts, especially "fixed pattern" noise from CCD array systems. Analysis of low light level images (speckle interferometry). Image formation of radio information, especially fan beam imaging, aperture synthesis applications and VLBI systems.
- **Scientific:** Scanning beam microscopy, electron microscope image enhancement, x-ray microscope image formation, molecular graphics display, automated cell counting, low light level detection and time resolved imaging. All modern microscope system equipped with digital cameras or digital video cameras connected to image processing computer.
- **Data Presentation and Computer Graphics:** Display of Computer Aided Design information, molecular graphics, seismic information display, object modelling and even computer games.
- **Communication:** Image compression for still and moving images. Image archiving and retrieval, secure image communication (electronic watermarking). Need for deal time systems.

- **Military:** Surveillance, guidance and tracking of objects (especially in the infra-red). Low light level imaging, range finding, image enhancement, reconstruction and display at all wavelengths, radar imaging, etc.

1.4 Digital Images

An image may be any two dimensional distribution of detected properties, this typically being the reflected or emitted radiation from an object. The detection process may be by photographic emulsion, analogue video, sensor arrays or scanning systems depending on the imaging system and the radiometric properties detected. The *image* may be either directly recorded in digital form, ie. by a sensor array or initially recorded by an analogue process (photographic or video), in which case the recorded image must be digitally sampled prior to processing.

When sampling an image, either directly by sensor arrays or from re-recorded analogue materials, the physical characteristics of the imaging system and the detectors must be considered. In particular the *Signal to Noise Ratio* (SNR) of the imaging system, the noise and quantization effects of the sensors, and the bandwidth of the sampling technique must be determined. A digital image is thus a collection of numeric values giving the image brightness at a series of sampled points. These points are typically arranged as a two dimensional square grid, but rectangular or hexagonal sampling structures are also possible. For all practical cases the sample points form a regular grid, although in some particular detector systems the sampling is non-regular, eg. in polar coordinates used in some radio telescope and computer tomographic systems.

1.4.1 Noise in Imaging System

Noise is present in all detection system, resulting from a range of sources such as: the discrete nature of radiation, thermal and electrical noise in detector system, scattered background radiation. In any particular system one noise source tends to dominate, for example in low light level astronomy the image noise is limited by the discrete nature of the detected light, while for TV inspection systems main noise contribution comes from electrical noise in the detector system. This introduced noise determines the information content of the images and the effect of many of the image processing procedures. To deal with noise a variety of statistical models have been developed, the simplest of which is based on Gaussian statistics. This topic will be dealt with in detail in Chapter 6.

1.4.2 Grey Level Sampling

When an image is sampled and digitised, the sampled points take on discrete (integer) values in a finite range. This range determines the dynamic range of the image, and has to be correctly chosen to avoid saturation. This is of particular importance in astronomical imaging where there are many orders of magnitude of brightness variation between a series of bright stars and an adjacent nebula. Monochrome images from video system and digitised from photographic material are typically digitised to 8-bits (256 grey levels), with full colour images represented as three monochrome images (red, green, & blue), each at 8-bits, giving 24-bits per pixel in total. Satellite images are frequently recorded as multi-spectral, consisting of 4—7 narrow bands, each of which would be digitised to 8-bits, thus giving between 32 to 56 bits per pixel.

For certain applications the 8-bits per pixels in not sufficient; this being particularly true for high quality CCD array detectors used on optical telescopes where the detectors are cooled to liquid nitrogen temperatures to reduce thermal noise. The output of these systems are frequently digitised to 12 or 14-bits (4096—16384 levels).

It should be noted that in many applications the dynamic range and SNR of the image is well below the typical 8-bits per pixel, but the images are usually digitised to this level since it matches the addressing structure of most digital computers and display devices. Thus if an image is digitised to 8-bits, there is no intrinsic guarantee that the data in the lower bits is significant; this must be determined from the physical properties of the imaging system. Also note that for video image capture, 8-bits per pixel is easily obtained with modest analogue to digital systems, but in excess of 8-bits involves very expensive, low noise systems.

1.5 Image Sizes

The size of the sample interval gives the number of image *pixels* digitised to represent the image. This gives the sampling frequency and thus the recorded bandwidth of the recorded image (*cf Shannon Sampling Theory*) covered in section 3. To represent all the information contained in the input image the image must be sampled at, or greater than, its bandwidth, where typically, the bandwidth is set by the imaging system.

1.5.1 Low Resolution Images

These are typically up to 640×480 pixels, corresponding to VGA computer displays. This is the highest resolution that can be obtained form video systems, (actually 768×586 for European video).

1.5.2 High Resolution Images

There is a range of high resolution images, including earth resource satellites at about 3000 by 4000 pixels, synthetic radar images at 3800 by 2800, colour separated images for commercial printing at 4000 by 4000, and computer synthesizes images for 35 or 70 mm movie at 8000 by 8000 pixels.

1.6 The Computational Problem

Digital images are held in computer system as arrays of numeric values where the values, or *pixels* represent an image "brightness" at each location. Images can range in size from about 256×256 pixels to 8000×8000 and being either monochrome or multi-spectral. Digital image processing therefore requires large computer resources both in terms of storage (memory and magnetic), and processor power. The algorithms to be applied to the images are typically computationally simple but the quantity of data involved causes major computational problems even for the most modest processing operations.

For the case of video images (UK standard), the Shannon sampling rate gives an image resolution of 768×568 pixels at 25 frames-per-second (allowing for interlacing). For a monochrome system, this represents a data rate of 6.5 Mbytes/sec. To process such images with a simple 3×3 linear filter (Chapter 4), would require a processor throughput of approximately 200 Mips. Therefore even this modest processing task either requires expensive general purpose hardware, or more commonly special purpose hardware designed to produce the desired image processing operation. However the algorithms used in image processing are conveniently developed and taught on general purpose computer systems, in high level languages (eg. Fortran or C), and then custom hardware developed if, and when the need for high speed processing arises.

2 Summary

This section outlines the main areas and applications of Digital Image Processing. Over the following chapters the image processing will be considered from an initially theoretical stand point, with more practical, problem driven applications, uses in the later chapters. This course is aimed at giving the reader an understanding of the mathematical and theoretical bases of Digital Image Processing, and in particular the limitations of the various algorithms. Throughout these notes the concept of an *image model* is used, which is taken to be the assumptions about the image statistics or structure. All image processing algorithms assume some type of *image model*, where this *model* is frequently inherent to the technique being used and is not explicitly stated.

Workshop Questions

2.1 Video Data Rates

When UK video standard images are sampled each frame consists of 768 by 586 pixels (there is actually 625 lines, but the some are user for teletext). Images are scanned at 25 Hz. Calculate the digital data rate of such a video signal.

A typical high quality graphics card in a PC will display 24 bit colour (8 bits red, green & blue), at a resolution of 1280 by 1024, with an refresh rate of 60 Hz. Calculate the data rate for this card and compare it with standard computer hardware.

2.2 Film Scanner

A high quality flat bed scanner, is capable of scanning pages **or** transparancies at 100 samples/mm (2400 dpi). It samples in 24 bits (8 bits red, green, blue). Calculate the size of the image file (in MBytes) if you scanned the following at maximun resolution.

1. A 35 mm colour slide (24×36 mm image area).
2. A 6×6 cm large format colour negative. (This is the format used by studio photographers).
3. A colour postcard.
4. An A4 page.

and comment of the answers you get.

You want to send 12 large format scanned slides by courier to a magazine editor, what computer media would you choose.

2.3 Tool for Displaying Images

You will be using the `xv` image display program to view digital images. There are a range of digital images located in

```
~ wjh/dia/images
```

that you should look at. These images are all monochrome and are in binary `pgm` format. They include simple gratings, fans, the “toucan”, the famous “lena” and a range of other images.

Use `xv` to look at these images and explore the use of `xv` to resize images, write as postscript (which you can print) etc. You will be making much more use of `xv` and these images during this course.