

ASSEMBLING A PC-BASED IMAGE PROCESSING SYSTEM:
SOME PRACTICAL CONSIDERATIONS

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CANADA
COMMISSION VI

ABSTRACT

Considering the general trend of supplementing and replacing conventional analogue photographs with digital images, educational institutions should plan for the acquisition of some appropriate digital image processing system. Today, several companies offer a wide spectrum of products with a large range of prices. The optimum hardware-software combination for an institution's particular needs is far from obvious. Many fundamental questions have to be investigated in order to arrive at a wise and justifiable decision. Those aspects of the pre-purchase phase are discussed with a description of one modest but adequate image processing system at the authors' institution, which is suitable for small groups of students.

1. INTRODUCTION

In 1964, the American space probe, Ranger 7, provided for the first time close-up pictures of the moon. The processing of these images marked the real beginning of the digital image processing revolution. Since then, several new applications and methods have been developed and today this field is flourishing. Numerous textbooks such as Gonzalez and Wintz (1987), Castleman (1979), Hall (1979) and Levine (1985) cover the subject in addition to the voluminous technical literature found in proceedings such as IEEE transactions, Electronic Imaging, Computer Vision and ISPRS archives.

Nowadays, digital image processing techniques are used in several spheres of activity, for example, electronic publishing, biological sciences, geology, robotics, to mention only a few. This tremendous development was triggered by the arrival on the market of new imaging boards which are ready to plug into inexpensive and wide-spread microcomputers. Indeed, in 1984 Imaging Technology Inc. came out with the first true frame-grabber for IBM PC-type computer (Weissman, 1987) leading to affordable digital image processing systems (DIPS). In fact, prices dropped from about \$100,000⁽¹⁾ for a DIPS based on an on-board image processing board to less than \$20,000 for a DIPS based on a frame grabber board with a host microprocessor (Gonzalez, 1987).

(1) All prices in this paper are in 1987 U.S. dollars.

An important part of the applications of digital image processing techniques is related to the spatial information concerning the visual scene.

This information can be recovered from the analysis of the geometry of two or more pictures taken from different angles. Photogrammetrists have a long established expertise in the geometrical analysis of analogue images and consequently, can play an important role in the conversion to digital images and get involved in these exciting applications and fertile research areas. However, in order to produce new graduates responding to current demands, surveying and mapping institutions have to consider the supplementing and replacing conventional analogue photographs with digital images. One of the first steps towards achieving this goal is clearly the acquisition of some appropriate digital image processing system.

On the market today, more than 70 manufacturers offer some kind of DIPS or related products with different degrees of sophistication for a wide range of prices (Wong, 1987). Consequently, the wise and justifiable choice for a particular institution is far from obvious. Several fundamental questions have to be investigated in order to select the right hardware-software combination. In the sequel, some practical considerations restricted to PC-based DIPS are discussed which should help the potential buyer of such equipment. Subsequently, an operational DIPS at the authors' institution will be presented as an example.

2. GENERAL DIPS COMPONENTS

As mentioned before, there are several different micro-computer-based DIPS currently available. These systems usually include the following basic hardware components (see Figure 1):

- camera,
- frame grabber,
- host computer and basic peripherals,
- image display monitor.

More sophisticated DIPS may also include the following items:

- image processing board,
- peripheral storage unit,
- video hardcopy printer.

In connection with this equipment, several software packages are available and, as with hardware, they generally have different levels of sophistication.

In the remaining part of this section, each of these individual components will be described, placing the emphasis on educational requirements.

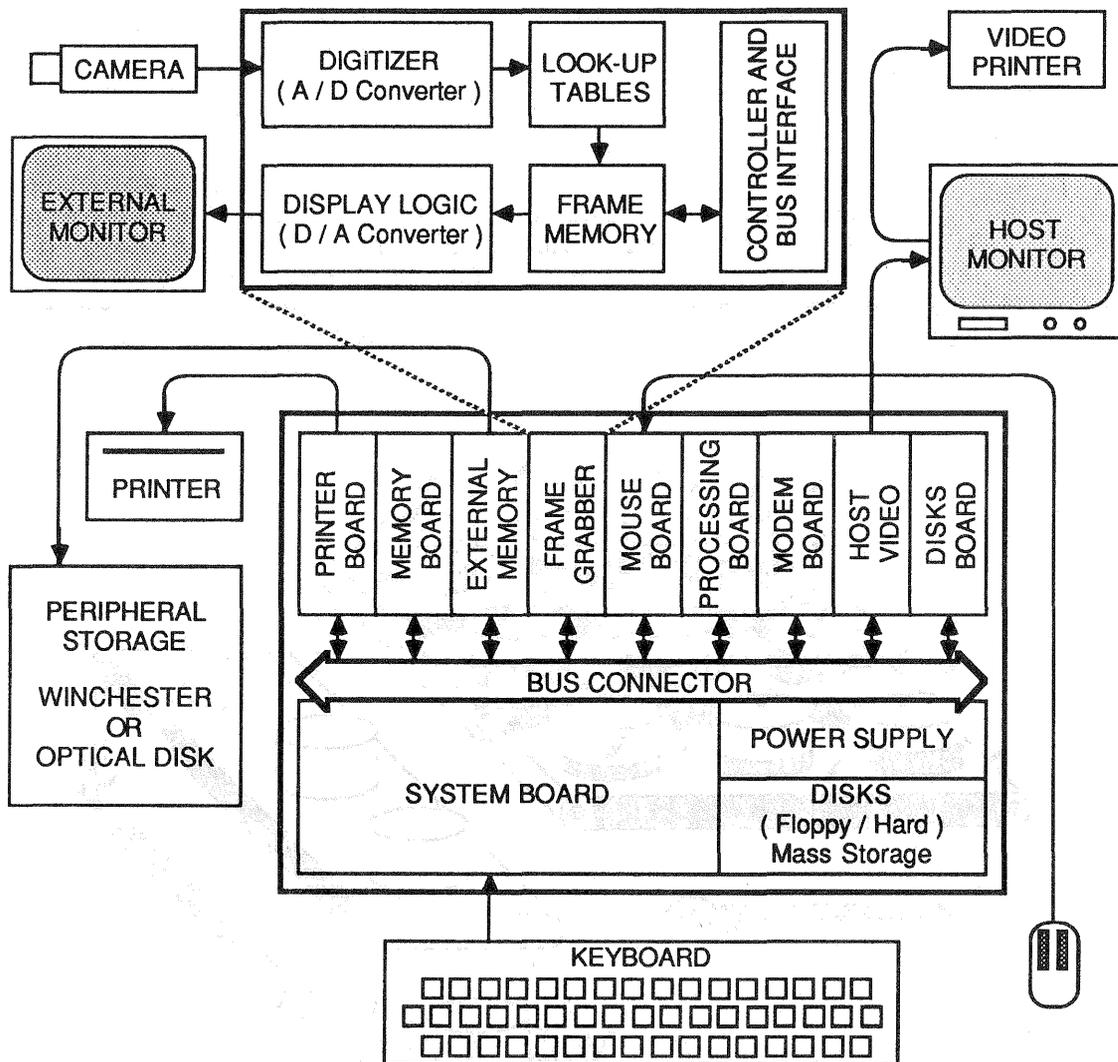


Figure 1
 Components of a PC - based DIPS, logical diagram
 (Adapted from Norton, 1986 and Imaging Technology User's Manual 1986)

2.1 CAMERAS

There are two basic types of digital cameras: Vidicon and solid-state. Both types produce a standard RS-170/330 (American standard) or a CCIR (European standard) TV signal. Vidicon cameras are based on vacuum-tube technology with an electric beam scanning a light-sensitive element to produce the image pattern. Solid-state cameras are based on semiconductor technology. The latter category includes two sensor types: Charge-injection devices (CID) and charge coupled devices (CCD). Sensors of the CCD type are by far the most used by manufacturers. CCDs are made up of an array of light-sensitive sensors which can be either metal-oxide semiconductors (MOS) or photodiodes. During operation, electric charges proportional to the amount of light falling

on each element are collected in capacitors and then transferred from the array in the form of amplified voltages to an analog to digital (A/D) converter. An elegant illustration to explain the operations of a CCD chip has been presented by Jerome Kristian of the Carnegie Institution of Washington; this illustration is reproduced in Figure 2 (from Janesick et al., 1987). This diagram shows an array of buckets covering a field. After a rainstorm, the buckets are transferred by conveyor belts to a collector where the amount of water is measured for each bucket. In the CCD's case the rain is replaced by photons and the buckets by small capacitors.

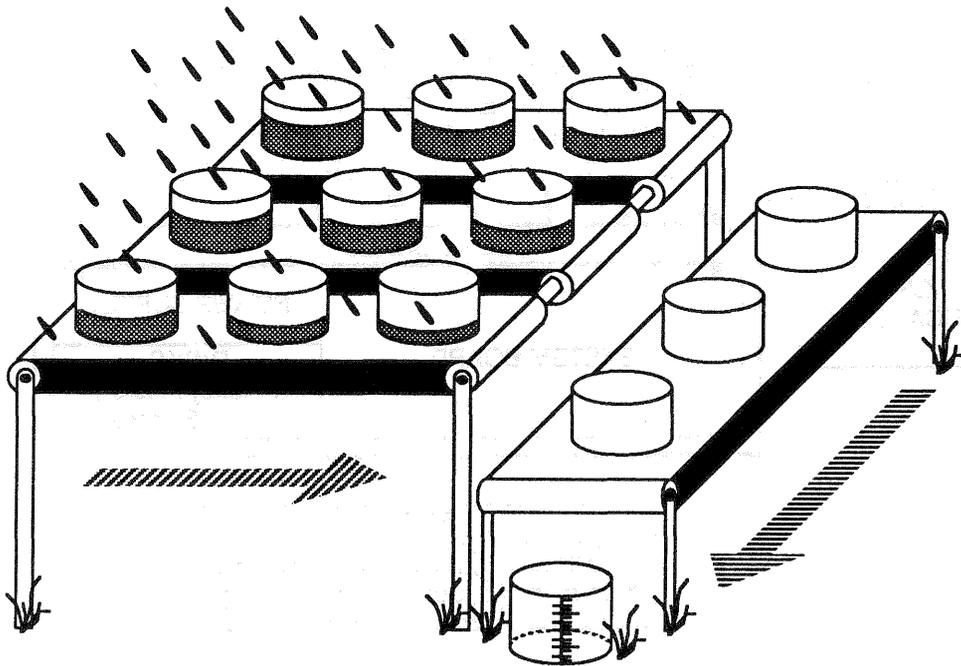


Figure 2
Schematic representation of a CCD's operation
(From Janesick et al, 1987)

The main advantage of CCDs over the conventional vidicon is the great stability of the picture elements, eliminating the need for fiducial marks to define the interior geometry. Usually the camera and the lens are sold separately. The choice of the lens must be a function of the future uses of the imaging system. For example, for very close range applications a macro-lens would be preferred. Another practical consideration that the future buyer should be aware of is the fact that certain camera bodies are built to receive C-mount lenses and others, only bayonet-mount lenses. An additional cost must be planned for the purchase of an adapter, if required.

One important CCD camera specification is the number of sensitive elements on the sensor. Generally, the larger this number is, the better the resolution. In practice, this

implies that with more pixels the signal will be more representative of the image projected onto the sensor. However, the effective resolution of an imaging system depends not only on the camera but also on the frame grabber. Since the output camera signal is resampled by the imaging board the effective pixel size is modified. The buyer should consider these two resolution defining elements together.

A last point concerns the number of cameras required for the DIPS. Again, this depends on the anticipated applications. If only two-dimensional information is needed, a single camera would be sufficient. Using two different camera stations, some stereoscopic tasks can be accomplished with only one camera. However, for real-time 3-D measurements, at least two cameras are required. More details about CCD cameras can be found in numerous publications (e.g., El-Hakim, 1986; Collet, 1985; Kosonocky and Sauer, 1975).

As an alternative to cameras, scanners can be used to digitize a printed image. This category of devices includes diverse products ranging from inexpensive low-resolution scanners (e.g., drum-scanners or flat-bed scanners) to scanners based on the new laser technology. However, in a digital image processing context, the scanner has serious drawbacks; the information is derived from already existing analogue image implying that an additional step has to be carried out. This may be of secondary importance in certain applications such as electronic publishing although this additional step introduces unwanted errors in the spatial information.

2.2 FRAME GRABBER

The main purpose of the frame grabber (see Figure 1) is to transform the analogue signal produced by the camera into a digital format through a process called digitization. The incoming signal is first amplified and filtered by the use of look-up tables to convert it to a television signal which is then sampled at regular time intervals. The sampling rate directly affects the global pixel size. For example, if the sample rate is twice as fast as the input pixel rate from the camera, the final pixel size will be half the physical size of the cell on the CCD sensor. During sampling, a digital value is assigned to each discrete sample according to the intensity and the range of the available gray scale. The gray level scale is frequently expressed as an 8-bit word yielding a range from 0 (black) to 255 (white). The pixel values are stored in the frame memory on the frame grabber board. Depending on the imaging board, one or two images can be generally stored in the frame memory.

The frame grabber also provides a way to display the contents of the frame memory. Using a digital-to-analog converter, the digitized signal is transformed back to an analog form compatible to the standard TV input of an external monitor. Finally, a module establishing the interface between the host computer and the board completes the frame grabber hardware.

Colour pictures can also be acquired with a combination of three different boards, providing that the camera sends red, green and blue signals. The cost of such DIPS would consequently be higher.

2.3 HOST COMPUTER

The computer, being the heart of the DIPS, can vary considerably in terms of sophistication and cost. A simple IBM PC compatible processor can easily drive all the components of a DIPS. Its main advantage is obviously its low cost but the execution time is somewhat slower than what a mini- or "supermini-" computer can offer. However, the speed is usually not a primary consideration in an educational context.

Nowadays, the vast majority of DIPS are based on the micro-computer of the IBM family, and compatibles. This family of PCs includes three types of computers: the conventional PC, the PC/XT and, finally, the PC/AT. All of them make use of an open type of architecture allowing the addition of many boards which are linked to the system board through a bus connector. The first two PC types have the same 8086 processor but the XT has an integrated hard disk. In the case of the AT, a faster 80286 processor is installed. An AT's computing power is equivalent to that of 5 PCs. The minimal requirement for a DIPS concerning the Random Access Memory (RAM) is usually 640 Kbytes. The internal clock speed for a classic IBM PC is 4.77 Mhz which is only 60% of the speed of the AT's clock (8 Mhz). For these reasons the selection of a PC/AT would be advisable. In addition, an arithmetic coprocessor (8087 for PC and PC/XT, 80287 for PC/AT) can be used to speed up the computations. Depending on the computational effort required by the software, the execution time may be reduced by a factor of 50 to 100 when using an arithmetic coprocessor.

There are no particular requirements for the host monitor. This device is only used to develop programs and display menus. However, there are some requirements for the mass storage capability with a DIPS. Knowing the relatively large amount of data involved in image processing operations (a 512 x 512 image requires 256 Kbytes, when stored without any image compression), it becomes obvious that one should acquire a large mass storage device. Due to the storage limitation of floppy disks (360 Kbytes to 1.2 Mbytes) they are not the best medium for storing the images. Hard disks are definitely preferable in this context. They are generally offered with a capacity of 20, 30, or 40 Mbytes. Considering the relatively small differences in price, buyers usually prefer a higher capacity hard disk.

Since several digital image processing software packages are written assuming the availability of a mouse, a few more hundred dollars should be reserved for this item. Completing the computer, a communication board and a modem are highly recommended in order to transfer data between computers. The communication facility (diskettes or modem) allows a large group of students to write and compile their code on other

micro-computers reserving the computer with the frame grabber for image acquisition and final testing of software. Finally, a printer is usually added to the previous equipment. The other elements of the computer logical diagram (Figure 1) which are standard features need not be discussed here.

2.4 IMAGE DISPLAY MONITOR

The image display should be considered as a window on the frame memory contents. Consequently, it must be possible to represent the image matrix properly. If the image stored in the frame memory is composed of 512 x 512 pixels, the monitor resolution should at least have this number of picture elements. Generally, a so-called high resolution monitor is needed and the usual resolution is of the order of 640 x 512 with 8-bit pixels. These monitors support also colour display (RGB) and are capable of displaying all the scan lines (non-interlaced). Newer monitors also offer the possibility of 3-D displays using, for example, polarized screens. The latter are obviously more expensive but open up another spectrum of possible applications.

2.5 IMAGE PROCESSING BOARD

Image processing operations can be classified in two classes according to the execution time required. The first class, called real-time, includes all image operations executable within the refresh time (1/30 sec). Among these are the DC restorations to ensure the image quality, the intensity transformations via look-up tables and hardware zooming. More complex operations requiring extensive computations such as Fourier transforms or convolutions fall within in the second class. Specialized hardware or processing boards for the second class of operations can be added to the DIPS significantly reducing the execution time. As mentioned before, adequate software could offer a slower alternative in the absence of proper hardware. To the authors' knowledge, very few image processing boards for IBM PCs are currently available.

2.6 PERIPHERAL STORAGE UNIT

If some research projects involve a large volume of image archiving, the PC-based DIPS can be expanded using a peripheral storage unit. At a cost of about \$10,000, a Winchester type can store 100 to 500 Mbytes or 400 to 2000 images of 512 x 512 with 8-bit pixels. More images can reside on the hard disk if some form of image compression is used (e.g., run-length encoding). Even though these numbers may seem impressive, the magnetic hard disk capacity is by no means comparable to the new technology in data storage: the laser-based disk. Indeed, an optical memory disk of 30 cm in diameter can easily hold 2 Gbytes (2×10^9) of data or, in terms of 512 x 512-8 bit pixel images, over 7800 images!

2.7 VIDEO HARDCOPY PRINTER

A special printer can be interfaced to the image display monitor to provide a fast and inexpensive means of obtaining hardcopies of images displayed on the screen. The quality of these prints is sufficient to allow the students to insert them in their laboratory reports, for example. For superior quality of prints, the possibility of taking photographs of the screen should be considered.

2.8 SOFTWARE

Along with the hardware, vendors also offer software packages or libraries of functions. These functions are callable from programs written in a high level language such as PASCAL, C and, sometimes, FORTRAN. Such libraries will save the students a great deal of the effort and frustration often encountered when dealing with the hardware details for the imaging board. Their code is generally very efficient and comes already compiled. Because they are hardware-oriented, the need for the educational institutions to have the source code is not of primary concern.

Some software firms also provide development packages or shells allowing the programmer to directly insert in a well-structured main program their development programs. In this case, the source code is provided by necessity.

3. THE DIPS AT THE UNIVERSITY OF CALGARY

Our modest DIPS is controlled by a Zenith ZW-248 (IBM PC/AT compatible) equipped with 1 Mbyte of RAM, a 20 Mbyte hard disk, a Zenith high-resolution colour-display monitor driven by an Enhanced Graphics Adapter (EGA), an 80287 math coprocessor, an Epson EX-800 printer and, finally, a Microsoft two-button mouse (total price ≈\$5,000).

The digital camera is a COHU 4810 CCD with an array of 754 x 244 light-sensitive sensors distributed regularly within an area of 8.8 x 6.6 mm. A Micro-Nikkor 55 mm f/2.8 lens is attached to the body camera with a C-mount adapter (total price ≈\$2,000). The image display monitor is a Mitsubishi 13" (33 cm) C-3479 high-resolution monitor (≈\$1,400).

Concerning the software, a development package from Infracan Inc. (≈\$300), a library of functions called ITEX written by Imaging Technology Inc. (≈\$650) constitute the basis of our own programs. The total price of this DIPS, including all the hardware and software, is about ≈\$11,900.

This new equipment has been satisfactorily used for one and a half years in the Department of Surveying Engineering at The University of Calgary. The needs at the institution are based principally on the application of the digital image processing techniques to surveying problems. Besides the instructional uses, this equipment is also utilized in different research projects such as: map revision with control transfer from

aerial diapositives to satellite imagery (Chapman et al., 1988), filter design for satellite imagery (Vassiliou et al., 1987), and image quality evaluation (Blais and Boulianne, 1988).

As a final remark, the authors would like to mention that the presentation of the previous equipment was not intended to suggest that the hardware and software named herein represent the best decisions today. The purpose of this exercise was to give an example of a DIPS and its price breakdown. Furthermore, the reader should keep in mind that this equipment was bought in December 1986, and for quite specific needs and requirements.

ACKNOWLEDGEMENTS

The authors would like to thank Mrs. Anne Gehring and Mr. Garth Wanamaker for their clerical assistance. This communication has been partly supported by a Natural Sciences and Engineering Research Council of Canada scholarship awarded to the first author and a Pilot Project grant from The University of Calgary to the last author.

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