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DIGITIZATION, DIGITAL EDITING AND STORAGE OF PHOTOGRAMMETRIC IMAGES

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ABSTRACT

The paper describes the advances in scanning technology for digital photogrammetric workstations. Depending on the actual applications, a number of scanners are currently available to convert analog photographs into digital images. Requirements for an integrated concept for digitization, editing and storage of photographic data within a digital photogrammetric system are presented and analyzed. It can be concluded that indeed operational digital photogrammetry will become the state-of-the-art for the future.

INTRODUCTION

In the past decade, developments in computer science, electronics and computer design have resulted in a meteoric growth of digital techniques for the disciplines concerned with geoinformation processing. The rapid development of high-performance graphical workstations coupled with operational successes of automated image processing have led to the widespread use of digital imagery in areas such as desktop publishing, document archiving or geographic information systems (GIS). It is therefore only consequent to investigate the potential of digital photogrammetric workstations (also referred to as softcopy photogrammetry) whereby the analog photographs would be replaced by digital imagery. Only four years after the introduction of the first prototypes at the 1988 ISPRS Congress in Kyoto, a number of vendors are now offering commercial digital photogrammetric systems (see table 1). In his observations of the 1991 Annual Meeting of the American Society for Photogrammetry and Remote Sensing (ASPRS), Donald F. Hemenway, Executive Editor of Photogrammetric Engineering and Remote Sensing stated "The hottest topic in Baltimore was softcopy photogrammetry" and noted that ASPRS has established a 'Softcopy Photogrammetry Committee' (Hemenway, 1991).

These commercial developments have been accompanied and indeed pushed by a number of successful R&D efforts at the academic level (see, for example, Gruen, 1989; Dowman, 1990; or Albertz et al., 1991).

Table 1: Examples of Commercial Digital Photogrammetric Systems

Manufacturer	Name	Processor	Stereo Display	Comments
Leica	DVP	PC	Prism Split Screen	Developed by Laval University
Leica	DPS	WS	Optical Split Screen	Developed by Kern
R-Wel	DMS	PC	Anaglyphic Full Screen	
Intergraph		WS	Dual Display Full Screen	
General Dynamics	DCCS	WS	Polarization Full Screen	Developed by Helava Ass. Inc.
Autometrics	Pegasus	WS	Polarization Full Screen	

COMPUTING TECHNOLOGY

Advances in computing technologies have been so rapid that it is difficult to evaluate the many alternatives offered today for high speed interactive computing. We have witnessed that the processing power of desktop workstations has nearly doubled every year. This development was coupled with decreasing hardware costs, the development of high resolution graphical screens with true color and/or stereo displays, the introduction of storage devices in the Gigabyte (Gb) range and improved network capabilities. It is predicted that only a few years from now CPUs capable of processing of more than 1000 MIPS (million instructions per second) will be common as desktop workstations (Faust et al, 1991). The recent introduction of Hewlett-Packards (HP) 700 series with its peak performance 66-MHz RISC processor of 76 MIPS demonstrates that we are only 3-4 'doubling cycles' away from this technology.

DIGITAL IMAGE ACQUISITION

Whereas computing power will to be able to handle large image files in an interactive mode, the capability to create images for such processing lags far behind. The direct acquisition of digital imagery where a two-dimensional CCD array replaces the analog film has not demonstrated rapid progress over the last decade. Geometric stability, signal-to-noise ratio and radiometric calibration do not pose significant problems with direct digital image acquisition. The major bottleneck in this technology is the insufficient number of sensor elements in the CCD array to capture information which would be equivalent to that in a standard aerial photograph.

The largest CCD arrays currently in use for digital image acquisition do not exceed 4,096 x 4,096 sensor elements (Luhmann, 1991). Consequently, this technique is primarily in use to replace small-format photography in close-range applications. According to Nyquist's sampling theorem, a standard aerial photograph with a resolution of about 40 lp/mm would require a sampling rate of about 10 μm in x and y direction to assure that there is no loss of information during the analog/digital (A/D) conversion process (Ehlers, 1984). To be equivalent to a format of about 23 cm x 23 cm, a CCD array size would have to be about 23,000 x 23,000 (=529,000,000 sensor elements) to capture the same amount of information as in a standard aerial photograph. Currently, we are still two orders of magnitude away from this number and progress has been rather slow in this area. Even if this this technology were available one has also to address the storage problem. Scanning a color aerial photograph at Nyquist frequency and an 8-bit per color radiometric resolution would result in a digital image of more than 1.5 Gigabyte (Gb).

The rapid acceptance of digital imagery, the promise of combining digital cartographic and GIS databases with up-to-date imagery, and the benefits of integrating graphic information with a digital image in a workstation environment, however, made it necessary to investigate alternative solutions to obtain high-resolution imagery suitable for photogrammetric workstations. The author has always promoted the concept of "If it's digital keep it digital; if it's analog keep it analog". With the slow progress in high-resolution digital image acquisition, however, the conversion of aerial photographs into digital format must be seen as a viable option for digital stereo workstations. The advent of low-cost desktop scanners for document archiving and desktop publishing has accelerated the trend to inexpensive and rapid image conversion.

SCANNING SYSTEMS

Essentially, there are three basic technologies in use for document scanning (Leberl, 1990):

a) Single Sensor Scanning: A single light-sensitive dot collects the light that is reflected off or transmitted through an instantaneous field-of-view (IFOV). A pixel array is assembled by continuous two-dimensional motion of the IFOV over the area to be scanned. This technique usually employs drum scanners where a step-motor defines the x-direction and the y-direction is controlled by the rotation of the drum. The early scanners that appeared about 15 years ago followed this technology.

b) Linear Array Scanning: A linear array of detectors simultaneously collects the light from up to thousands of linearly arranged IFOVs. Again, reflectance or transmittance scanning is possible. The two-dimensional image is assembled by continuous motion of the detector array or the document to be scanned. Individual linear profiles may be assembled into a wider array. Examples for this technology are the desktop scanners.

c) Two-dimensional Array Scanning: A two-dimensional array of detectors is used to collect light from a 2D array of IFOVs (frame grabbing). The CCD array is in a stationary position and the image is formed instantaneously. A larger array of pixels may be assembled from individual frames ('tiling'). Examples for this technology are CCD-videocameras.

PHOTOGRAMMETRIC REQUIREMENTS

A number of scanners are currently being used to convert analog material into digital images. Performance, prices and formats show a great variability. In a cartographic study, Bosma et al. (1989) investigated low-cost desktop scanners with a maximum radiometric resolution of 6 bits and concluded that "low-cost scanners are limited by their instability, resolution or format". Using control points for adjustments, accuracies of about ±0.2 mm could be achieved. At a relatively low scanning frequency of 300 dots-per-inch (dpi), this already amounts to an accuracy of about ±2.4 pixels which is certainly not suitable for further photogrammetric processing (i.e. automated correlation, aerotriangulation etc.).

For close-range applications, however, Benning and Effkemann (1991) concluded that photographic enlargement and reseau techniques could be used to employ standard 300-dpi desktop scanners for efficient digitization. Despite their efforts, however, the reported accuracies were still in the range of 80 μm (0.8 pixel).

What are the requirements that these systems would have to meet to be used as scanners in a 'general purpose' digital photogrammetric environment?

A. Geometric resolution: Desirable would be a variable resolution with 'zoom-in' capabilities; Maximum resolution should be in the range of Nyquist frequency sampling for aerial photographs, i.e. ~10 μm (~2500 dpi).

B. Radiometric resolution: In compliance with current technology, 8 bits (256 grey levels) per color are required to allow easy integration with state-of-the-art remote sensing systems. In some cases, 6 bits (64 grey levels) might suffice. To assure maximum geometric precision, color scanning should be done in one swath (24-bit scanning).

C. Scanning format: Maximum scanning format should allow full-frame photographic data capture, i.e. 23 cm x 23 cm. Low-cost desktop scanners are of limited suitability as they comply mostly with standard document sizes of A4 (Europe) or 8.5" x 11'' (US). An aerial photograph would have to be cut for scanning which would require subsequent digital mosaicking. In addition, the

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fiducial marks would be digitized in separate scans thus not permitting precise geometric processing.

D. Conversion technology: Experiments have shown the inherent geometric instability of drum scanners which make them unsuitable for photogrammetric use (see, for example, Boochs, 1984; Neukirchner, 1989). Slowly rotating drum scanners employing linear CCD array technology might improve these deficiencies. For CCD scanners, there seems to be no noticeable difference in quality between linear and two-dimensional arrays.

E. Geometric accuracy and precision: This requirement is of critical importance for photogrammetric processing. Geometric accuracies should be in the range of less than a pixel per full frame whereas precision values should be an order of magnitude better, i.e. about 0.1 pixel. Otherwise, sophisticated photogrammetric techniques such as aerotriangulation or bundle block adjustment with robust estimation would be wasted on inappropriate image material. As shown before, most standard desktop scanners cannot provide these accuracies.

F. Suitability for photogrammetric processing ('intelligence'): To avoid additional computations, the systems should be able to automatically or interactively detect the fiducial marks to perform an interior orientation. This would assure that each pixel in the image can be related to the photo coordinate system without further processing. If other a priori knowledge is provided the system should be able to integrate this knowledge in the scanning process. An example would be epipolar scanning based on exterior orientation thus alleviating the need for costly resampling in order to perform automated correlation for digital elevation model (DEM) extraction.

G. Price: This is probably the most critical issue for the final acceptance of digital photogrammetry. Unless digital systems can be less expensive than existing analytical plotters (but exhibiting similar performance), the new technology will not be widely accepted. A complete softcopy photogrammetric system with a high-end graphical stereo-screen workstation of sufficient memory, disk storage and computing power together with a high-precision scanning subsystem should not cost more than today's analytical plotters.

H. Speed: Similarly to point G, the speed of a scanning system should be high enough to compete with current analytical technology. Interactive scanning must be feasible.

The ultimate photogrammetric scanning system should be balanced as usually the weakest link in a chain defines the usability. Table 2 list a number of current scanners available for digitizing photographic images.

EDITING, STORAGE AND ARCHIVAL

Even if digitization can nowadays be accomplished in an almost interactive mode, requirements for subsequent processing (i.e. bicubic resampling, automated image matching etc.) are currently defining the bottlenecks of real-time digital photogrammetry. Some intelligence in preprocessing such as interior orientation and zoom-in into areas of interest are already existing features in more sophisticated photogrammetric scanners (e.g., Photoscan, HAI-100).

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Table 2: Examples for Image Scanning Systems

Vendor	Scan Format 1)	Max. Resolution Geom. 2)	Radiom.	Digitizing Technique	Accuracy/ Precision 3)	Photogramm. Intelligence	Max. Speed 4)	Price 5)
EIKONIX 1412	no restriction	5x7	12 6)	4096 CCD	10/2		1,000	25,000
HAI 100	24 x 24	10	8 6)	2D array	3/1	Int. Orientation		135,000 8)
Joyce-Loebl Scandig 2605	30 x 40	25	8 6)	drum scanner	?		100	
Sharp JX-600	28 x 43	42	10 6)	linear CCD	?		200	15,000
Tangent CCS-TR	30 x 50	25.4	8 6)	linear CCD	10/5	Enhancements	3,000	80,000
Vexcel VX 3000	25 x 50	8.5	24 7)	2D array	4/1	Reseau	500	50,000
Zeiss/Intergraph Photoscan	25 x 25	7.5	8 6)	2048 CCD	2/1	Int. Orientation	2,000	100,000

1) In cm x cm; 2) in μm; 3) in μm; 4) in Kpixels/sec; 5) Approximate Price in US$; 6) Bits/color (three- or four-pass scanning); 7) 8 bits/color (one-pass scanning); 8) Price includes DCCS Photogrammetric Workstation and Software

With the continuing 'explosion' in computer power, however, these constant requirements will very likely be met in just a few years from now. The use of specialized hardware such as array processors and transputers will probably only be necessary for a transition period. Strategies to keep the digitized image in the raw format on disk and just resample the area necessary to be displayed on the screen may also be used as long as computing power does not allow interactive resampling of a full frame. Other computer intensive tasks such as stereocorrelation might me run off-line or overnight to free up the systems for interactive processing.

Current workstations already offer random access memory (RAM) options of up to 500 megabytes (Mb). As the trend to memory upgrade will continue it is again just a question of time when a full 23 cm x 23 cm photographic image scanned at Nyquist frequency can be kept in memory allowing free roaming and zooming through an entire photograph.

An area of relatively slow improvement has been the speed of disk access. Although Gigabytes of data can be stored on-line, the access to the data on disk has been rather slow compared to computer power and possible bus transfer rates. However, the increase in RAM might make up for deficiencies in on-line disk access. For long-term storage and archival, Optical devices, digital audio tape (DAT) or even videotape technology provides inexpensive and easy-to-use alternatives to magnetic tapes. Also, progresses in network technology will likely allow centralized storage with decentralized access and processing a state-of-the-art of the future.

CONCLUSION

Advances in computer hardware and software, image processing, digital cartography and GIS, and relatively low-cost scanning solutions are leading to the development of operational digital photogrammetric systems. In using digital image processing techniques, boundaries between remote sensing image analysis and digital photogrammetry will be hard to define. The emergence of standards and the ever-increasing processing, storage and display capabilities of modern RISC based CPUs will allow even more integration in the future. Digital photogrammetry as part of a general geoinformation processing system will be the state-of-the-art of tomorrow.

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