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The Promise of Softcopy Photogrammetry

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ABSTRACT

As graphics workstations and computer stereo viewing devices become commonplace and available from $5,000 upwards, it is software and systems integration that are needed to configure highly competitive photogrammetric measuring systems. The field of photogrammetry is aware of the erosion of the role of the analytical plotter and specialized photogrammetric equipment industry. It appears that this will be succeeded by software vendors, systems integrators and the digital photogrammetric workstation. The following are preconditions for the acceptance of softcopy systems into photogrammetric practice:

* end-to-end digital systems need to be configured;
* softcopy needs to move from small scale satellite image processing to large scale film-based systems;
* clear economic advantages must be persuasively demonstrated.

None of these require breakthroughs. The advantage of softcopy photogrammetry is already a fact, even if not generally recognized or accepted. Throughput advantages in excess of 40% can be demonstrated, and cost is currently comparable to analytical plotters, with a soon-to-be evident large cost advantage over analytical photogrammetric systems.

The paper presents the "ideal" digital photogrammetric workstation as an end-to-end system for production of spatial data, it reviews the status of current systems-offerings on the market, and it examines the changes that the transition to digital image processing may mean to photogrammetric practitioners.

1. BACKGROUND

We look back at a 70-year history of analog photogrammetric systems, beginning with v. Orel's stereo-instrument and Pulfrich's stereo measuring mark (Manual of Photogrammetry, 1980). We also look back at only 20 years of analytical photogrammetric instrumentation, which took hold since the early 1970's, although its principles of operation go back to the mid 1950's (Helava, 1958).

We now live through the transition to digital photogrammetric systems that invalidates some of the previous technologies. In the process we see the entire field being transformed. As we abandon the photograph on film as a so-called hardcopy image, and find us confronted with a digital pixel representation in softcopy form, we get confused even by the nomenclature. Instead of using the often-emplyed sequence of analog-analytical-digital photogrammetry, we prefer to use the term "softcopy photogrammetry" for that branch of photogrammetry that deals with digital pixel arrays instead of film. We set it apart from all previous implementations, be they called "analog" or "analytical". After 70 years of analog and 20 years of analytical systems, how long will we speak about softcopy photogrammetry?

1.1 Innovation in Photogrammetry

Not only do we experience a change in the manner in which photogrammetry processes its data, going from hardcopy to softcopy. We also are confronted with new types of sensors, be they digital devices, operating in invisible portions of the electromagnetic spectrum or with sound. In addition these sensors are being tracked with great accuracy and provide us with instantaneous positioning of sensor platforms.

The deliverable data products from a photogrammetrist's efforts are subject to a redefinition through the transition from the map to the Geographic Information System (GIS), thereby dramatically reducing the life-cycle of the data products. Finally, from a well-defined specialization with a routine task of creating national map series at specified scales the practitioner of photogrammetry is thrown into a new role of member in multi-disciplinary teams tracking *phenomena* and supporting complex, often political decision processes with near-instantaneous data support.

In short, all familiar elements and concepts of the field of photogrammetry are subject to radical reevaluation and redefinition. This can rightfully be called a *revolution*, although it may appear that the revolution is becoming institutionalized.

1.2 Defining a Position Vis-a-Vis Current Changes in Photogrammetric Technologies

It is a challenge to define a concise and meaningful position vis-a-vis these changes, as this contribution wants to do. We experience simultaneity of the new and old to an extent probably never in existence before. The photogrammetric equipment industry is in turmoil; traditional academic centers of learning in photogrammetry just come from absorbing the new wave of remote sensing, and now must submit to the innovation pressures of digital image processing.

Softcopy photogrammetry as a successor to hardcopy film-based photogrammetry provides thus just for a component of a bigger development. In this paper we will look at this narrow subject with an eye on the opportunities of softcopy photogrammetry, addressing this from four vantage points. The purpose of the discussion is to

(a) Clarify why we must vigorously accept pixel-based photogrammetry;

(b) Sketch the issues that may confront the photogrammetrist as the field transits towards a specialization of applied computer science.

This contribution is therefore not a technical paper, but a position paper defining a view of the current revolutionary developments in photogrammetry.

2. FROM ANALYTICAL TO SOFTCOPY PHOTOGRAMMETRY

2.1 Definition

Softcopy refers to a representation of text, images, symbols and other data in the computer in digital form. The representation on paper or film is referred to as *hardcopy*.

Softcopy *photogrammetry* is the technology of photogrammetry applied with imagery in the computer. There is, however, no concept of *hardcopy photogrammetry* , only of analytical and analog photogrammetry to designate the use of film-based imagery.

The change-over from analog to analytical photogrammetry did not result in new principles and results, just in *evolutionary* improvements of the productivity and accuracy of photogrammetric processes. The transition from analytical to softcopy procedures initially appears also as just an implementation of traditional capabilities on a new "platform" or vehicle. Thus all the conventional processes of photogrammetric engineering continue to be applied and produce the same conventional products: point coordinates, map manuscripts and orthorectified imagery.

We will argue, however, that this is only an *apparent* situation; in reality, softcopy photogrammetry will reveal itself as a *revolutionary* innovation (Fig.1).

Evolutionary Revolutionary

Analog ----------------------------> Analytical -------------------> Softcopy
70 Years 20 Years ? Years

1900---------1970 1970----------1990 1990----------?

Figure 1: From analog via analytical to softcopy photogrammetric technology.

2.2 Acceptance of the Technology

There currently exist probably in excess of 15 vendors of softcopy systems (Table 1), not counting the experimental implementations in research institutions, nor specialized real-time systems operating with multiple digital cameras. This is a very large offering when comparing it to the current population of four or five traditional photogrammetric equipment vendors. There is no question that softcopy photogrammetry has arrived as a fully operational technology.

However, this large offering of available systems is not proof that the current users of photogrammetric services and equipment also *accept* the new products enthusiastically. The contrary is true. While several hundred PC-based softcopy stereo systems may currently already be in use, this seems largely outside traditional mapping applications. Typically the mapping industry is rather conservative and acceptance is but slow. This coincides with the picture that was offered in 1972 and subsequent years, when the analytical plotter was being offered, but was hardly being employed in the daily practice of photogrammetry.

This slow acceptance is a direct consequence of the lack of clear advantages that initial softcopy systems offer over currently used analytical systems. Hardly any automation is operational. *No* digital elevations models (DEM's) can be generated with high quality by automated image matching: attempts to automate typically are contaminated by bad matches so that manual fixes are needed , thereby destroying any throughput advantage the automation may have promised[1].

1. Conclusions drawn from discussions at the ISPRS WG II/III Workshop on "Design of Digital Photogrammetric Workstation", Boulder, Colorado, March 1991. Papers of this workshop appear in Photogrammetric Engineering and Remote Sensing, January 1992.

Table 1: Current commercial offering of softcopy photogrammetric systems (Status spring 1991)

Vendor	Product	Platform	Comment
Intergraph	MGE/Images	Clipper/Unix	Orthophotos from external DEM image processing
I²S	Prism	SUN/UNIX	Orthophotos from external DEM, non-stereo
MDA	Geomate	SUN/UNIX	Ortho-photos, map updating
Autometric	Pegasus	SGI/UNIX	Full stereo system including orthophotos
R-Wel	DMS	PC/MS-DOS	Full stereo system, particular uses for satellite images
DVP Photogrammetric Systems	DVP	PC/MS-DOS	Full stereo system, no orthophoto, employs end-to-end integrated system with scanned aerial photography
VTA	VMAP	PC/MS-DOS UNIX	Split screen stereo, monoplotting X-Windows
Galileo	Orthomap	PC/UNIX	Orthophotos, non-stereo
Matra	Traster-T10	SUN/UNIX	Full stereo system includes orthophotos and DEM, proprietary real-time boards
Topcon[1]	PI-1000	PC/?	Softcopy stereo viewer combines with PS-1000 scanner
Leica	DSP-1	DEC/VMS	Full stereo system, uses GEMS Image Processor
Vexcel	SSCS	Stardent/UNIX	Full stereo system for radar images, radar-orthorectification
ISM	SYSImage	PC/MS-DOS	Ortho-Photos from external DEM, nonstereo, runs within Microstation
Helava Ass.	HAI 500 HAI 750	PC/UNIX SUN/UNIX	Full stereo system, PC uses Parallax board and SUN uses VITEK board for stereo and acceleration
Laserscan/UCL[2]	TBD	SUN/UNIX	Full stereo system, creates DEM and orthoimages, uses Transputer system

1: Data as of mid-1988; 2: Commercial system is currently under contract, but not yet completed.

Automation has also not been successful in the extraction of planimetric mapping data, although some research is being reported that promises that automated feature extraction will ultimately be useful (Perlant and McKeown, 1990).

The *only* automation that reliably produces successful products is the ortho-rectification: mostly the DEM for orthorectification is externally provided and a digital orthophoto can routinely and inexpensively be produced from softcopy input. We therefore also see that acceptance of softcopy systems begins with the digital orthophoto. However, we need to realize that orthophoto generation has been a successfully automated process, in fact the only one, since its beginning.

2.3 From Stereoplotters to Film Scanners and Recorders

The transition from analog/analytical equipment to softcopy photogrammetric systems removes the need for specialized equipment. Hence a specialized photogrammetric equipment industry ceases to be in existence. However, the major source of imagery, also for softcopy photogrammetry, remains the aerial photograph. The need exists therefore to convert the photographs into a pixel array using a film scanner; and the orthophoto needs to be recorded onto film, creating a need for film writing equipment. As the photogrammetric equipment industry fades, an industry for scanners and film recorders will flourish.

2.4 What is Needed to Ensure Rapid Acceptance of Softcopy Photogrammetry

We are already seeing a certain degree of acceptance of the new offerings in digitial photogrammetric systems, mainly in non-traditional applications. The digital orthophoto is becoming a routine add-on to the GIS (see Chapter 4).

However, a full breakthrough requires that current offerings of softcopy systems become fully integrated end-to-end *applications solutions*, and include image generation, scanning and output creation. This integrated solution must offer full advantages over the current equipment and procedures, which often cannot yet be demonstrated.

Therefore the acceptance of softcopy photogrammetry into every-day practice will require that the promise of automation be implemented. This must permit to have less-well trained operators perform at levels near those of traditional and experienced operators, that throughput be significantly increased and that cost/benefit advantages become evident.

However, even without automation, significant throughput advantages may become feasible. In an instance concerning routine stereo-DEM generation from radar iamgery, Leberl et al. (1991) report a 40% throughput advantage of a softcopy system over the same task performed on an analytical plotter DSR-11.

3. TOWARDS A SPECIALIZATION OF IMAGE PROCESSING

In the computer sciences there exists a sub-area denoted as Image Processing and Computer Graphics. This terminology at times is used as an umbrella for a series of further specializations to include image pattern recognition and image understanding.

Traditionally, photogrammetry has been defined as a technology and drew a "right-to-live" from its application to *mapping*. Photogrammetrists always were experts of the mapping field, in spite of many examples to also take root in medicine, architecture, industry. In the age of softcopy photogrammetry, the definition as a technological specialty is eroding and being substituted by a specialty in digital imaging and image processing.

With the transition of photogrammetric systems to softcopy solutions, a typical (if not "ideal"?) photogrammetry workstation will be configured as shown in Figure 2. The only concession to photogrammetric technology are the software and algorithms, but no photogrammetric hardware is being used. One may thus argue that photogrammetry is defined as a set of algorithms residing on generic graphics computer workstations, and a "manual" describing the required photogrammetric expertise.

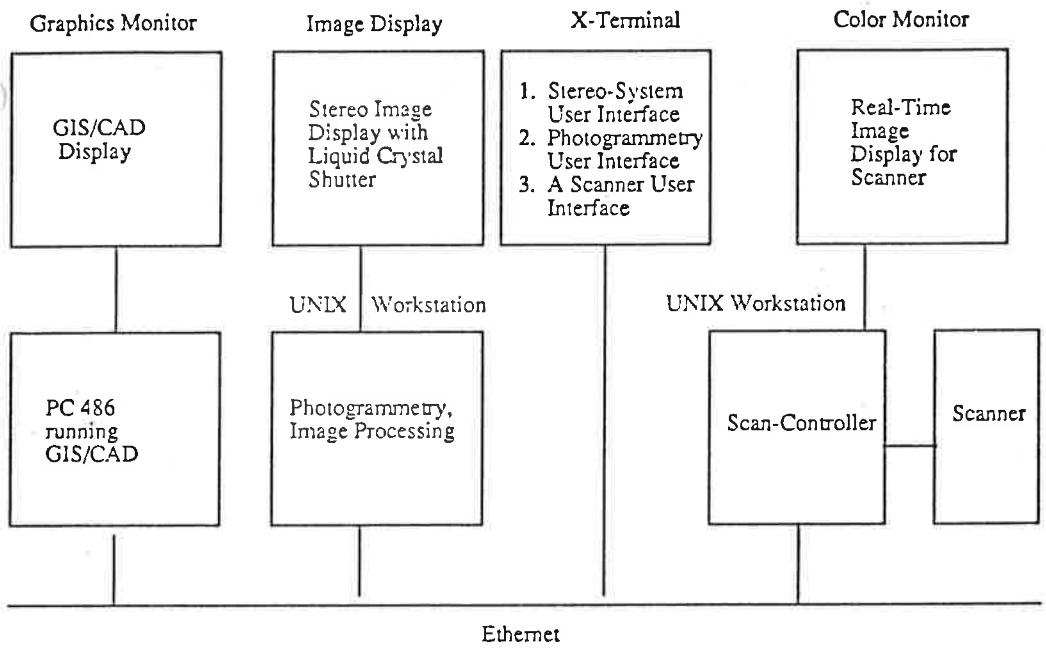

Figure 2: Typical configuration for an end-to-end softcopy photogrammetric workstation.

A typical workstation design will start off by connecting several digital workstations. At computer costs well below $5,000 it is likely that one will use several CPU's for different tasks, instead of sharing one CPU for several tasks. Therefore it is suggested to have the stereo-operator console arranged separate from the GIS/CAD display station. The issue whether the stereo-operator console be single- or dual- "headed" is simply one of convenience. At costs for X-terminals well below $2,000 this item simply is not important. Stereo-viewing of softcopy images has also become a low-cost item, since CAD has become a market for mass-produced stereo-attachments[2].

3.1 Integrating the Scanner Function

In an integrated *applications solution* we must address the graphics data (GIS/CAD) *and*

2. In the event of one computer vendor, Silicon Graphics Inc. (SGI), stereo-viewing is prebuilt into each workstation and can be activated for less than $4,000, using the Stereographics technology.

the image input/output. It is suggested that the film scanning subsystem be made part of the design. The scan controller can be operated from the same user interface that the stereo operator employs, running the scan application in a window on the X-terminal. Data can freely move over Ethernet to any disk and CPU on the network. Resolutions, areas of interest, coordinate systems etc. can be selected per project on the spot.

3.2 Value is in the Software

The photogrammetric capability has become a software package, capable of executing on a large range of graphics workstations. The surviving value lies in some basic photogrammetric and image analysis functionality that can be broken into modules:

(a) Manipulations of images.
These are the "light table", "stereoscope" or "stereocomparator" functions.

(b) Real-time mathematical sensor model.
This is the function that connects the 3-D mouse with the two 2-D cursors of the stereomonitor.

(c) Coordinate processing.
Routine photogrammetric inner, relative, absolute orientation, approximate value generation, block adjustment etc.

(d) Graphics module.
Data collection for point, line, symbol digitization, and stereo-superposition.

(e) Interfaces to GIS/CAD.

(f) Digital Elevation Model (DEM) processing.
Data collection, error checking, gridding, contouring, visualization, editing.

(g) Automation modules.
For image matching, line following, texture mapping, image classification etc.

(h) Image rectification.
Creating node points based on a sensor model and DEM.

(i) Image resampling.
Create an ortho-image from the raw digital image and node points.

(j) Image processing.
Modify the softcopy images to be better suited for display or analysis.

The strictly photogrammetric elements in the softcopy system are the real-time sensor model and the coordinate processing modules (elements (b) and (c)). We may well conclude that the parent discipline is computer science, image processing and graphics are a specialization and photogrammetry is a particular *tool box*, possibly even a *black box*, of rather small proportions in the larger scheme.

4. GIS - PHOTOGRAMMETRY

Viewing photogrammetry as a mapping specialty of course continues to be valid. However, it may be worthwhile to look at the major changes in the mapping application in its transition to the Geographic Information System, and how this affects photogrammetry.

The GIS creates a new set of requirements for image-based data. This addresses three issues:

(a) extraction of information from imagery to be used in a GIS data base;

(b) providing the image itself as an information layer as part of a GIS data base;

(c) creating a GIS updating mechanism.

We denote the technology surrounding these issues with "GIS - Photogrammetry", to keep it apart from traditional topographic photogrammetry. In an end-to-end GIS one needs to consider the data source as well as the data uses. The traditional view is to keep the data collection in a separate set of procedures (photogrammetry) and consider the GIS in analogy to traditional cartography. We object to this view and propose that the images become a native data layer in every GIS.

4.1 The Image as Part of a GIS

The image may affect the type of data to be *extracted* from imagery, particularly its detail and accuracy. The addition of an image to the GIS as an information layer will also have an effect on the user who now may be able to pose queries to the GIS previously unavailable since the image represents information otherwise not available.

The image in the GIS of course is in a digital form. Digitization may be of entire image coverages, or of only an instantaneous field of view using a digital camera viewing a hardcopy photograph. The latter case poses the problem of maintaining the necessary coordinate relationships. A solution has been described by Rosengren and Williams (1991). If an entire image is being stored in digital form then issues of resolution, access and geometry need an answer: is a raw image of use or does it have to be rectified into a digital orthophoto?

Clearly the most recent developments in GIS-technology create a need for a digital orthophoto and several commercial sources of such data are available (see Table 1). The data quantity that can be used is still at times limited to perhaps 5,000 x 5,000 pixels per aerial photograph, resulting in a need to scan a 23cm x 23cm photo with 50 µm pro pixel, or use digital source material (SPOT, LANDSAT etc.). Ultimately, high-performance workstations need to be able to resolve the information content of aerial photographs with pixel sizes of 5 to 10 µm, and image sizes of 23,000 x 23,000 or 46,000 x 46,000 pixels.

4.2 GIS - Updating

Traditionally the map-user had no interaction with the map-making process. Map-updating was strictly another specialization far removed from the user. The GIS, since it relies on softcopy data only, holds promise to change all that. As the GIS-analyst discovers an inconsistency in the data base or a need to update it, the ability exists to do so *and to affect* all other users of the data base in a networked environment. This is particularly feasible if *new imagery* is part of an (old) GIS data base. The user can be integrated into the updating process, as long as data access and change authority are defined.

There is of course also an opportunity to automate the *updating* process, with a likelyhood of success that is greater than that of automating the original feature extraction from photography. The concept is to *project* the old GIS objects into the new digital pixel array and to verify the validity of the old data base entry (Fig.3). Inconsistencies can be flagged or removed. New objects, if available from the imagery, can be added.

However, the mere ability to rely on an image-base as part of the GIS may make the need for updating a lot smaller. The new imagery at low renewal cost provides the latest status of a study area. There is a reduced reliance on old GIS data.

5. PHOTOGRAMMETRY OUTSIDE THE MAPPING APPLICATION

The transition to digital sensing via video-cameras and CCD-array sensors, and the ability to process such images or scanned versions of conventional photographs in inexpensive computers has led, and continues to lead, to a rapid growth of uses of photogrammetric tools (Grün and Baltsavias, 1990). A concise formulation for the reasons for this growth is the *democratization* of photogrammetry.

Abandoning complex analog or still-mysterious analytical photogrammetric devices, and substituting for them the perceived simplicity and ubiquity of the computer workstation, leads to a surprising acceptance of photogrammetry. Combined with "shrink-wrapped" photogrammetric tool boxes one can expect that photogrammetry will finally fulfill its century-old promise for non-topographic application.

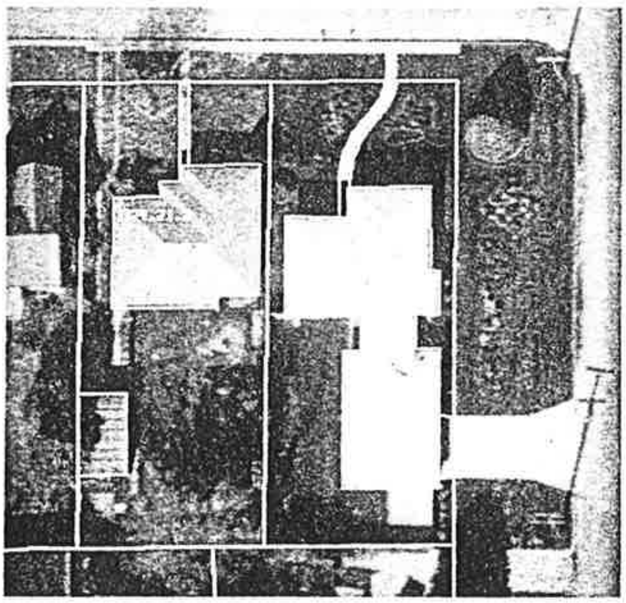

Figure 3: Image and GIS data can support the automation of GIS updating by projecting GIS/map data onto the pixel array, and then to verify the validity of the GIS data entries.

6. SENSORS AND PRODUCTS

6.1 From Digital Images to Image Cubes

We have a dramatic broadening of the range of image sources for softcopy photogrammetry compared to the traditional situation with analog or even analytical photogrammetry. Of course, the transition from analog to analytical systems was originally driven by the need to deal with non-conventional film-based imagery from military cameras. Commercially this ability of analytical systems has never been important, although systems were configured to map from SPOT (Gugan and Dowman, 1988), radar images (Raggam and Leberl, 1984) and other non-traditional sources.

The range of new sensors does not only include the electro-optical satellite systems (SPOT, Landsat, StereoMoms, Japanese ERS-1), or the satellite radar imaging devices (SIR-C, E-ERS-1, J-ERS-1, Almaz, Radarsat), but also the new high resolution spectrometers such as AVIRIS, HIRIS and MIES with 220 and more images produced per coverage. A 10km x 10km area at 10m pixel size results in a 220 Megabyte file representing an *image cube*.

Similarly, many remote sensing studies increasingly rely on co-registered images from different times, sensors or sensing parameters, again evolving into the image cube concept.

These data sets require significant sophistication in image pre-processing using precision co-registration, and in the ability to manipulate very large datasets. Modern visualization technologies represented by AVS, Linkwinds, PV-Wave[3] can support the analysis of such data sets, resulting in a processing concept as described in Figure 4.

The planned Earth Observing System (EOS), with satellite launches from 1997 onwards, is expected to cover the entire globe with multiple spectral coverages and 12-channel radar images, producing an unprecedented quantity of environmental observations.

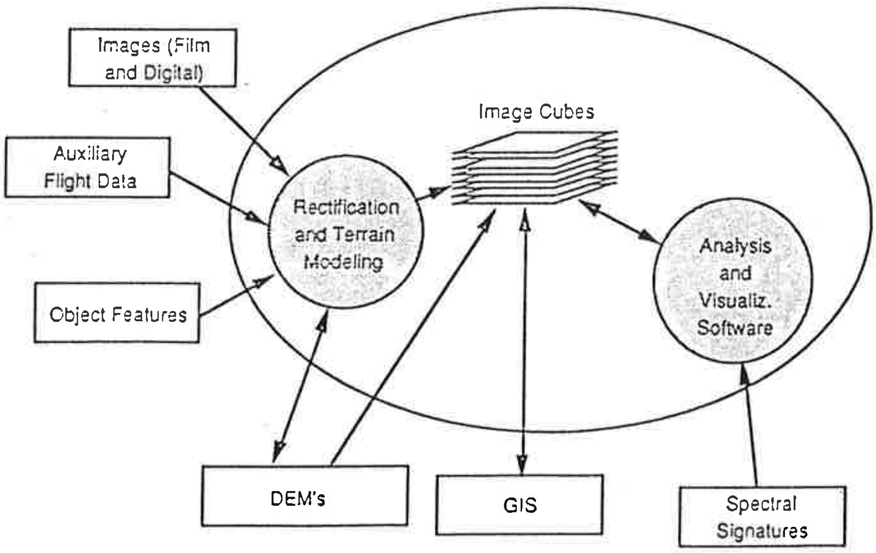

Figure 4: From images to image cubes and data visualization.

3. AVS is a software system of STARDENT Computers, Newton, Massachusetts. Linkwinds is an experimantal image and graphics visualization software package created by A. Jacobson at the Jet Propulsion Laboratory, Pasadena, California. PV-Wave is a commercial software product for data and image visualization by Precision Visuals Inc, Boulder, Colorado.

6.2 New 3-D Sensors

Several new satellite systems are expected to produce novel types of stereo images with forward/downward/backward looking linear array sensors. This results in an ability to reconstruct the object shape in an automated manner that is more reliable than previous satellite stereo systems (Ebner and Kornus, 1991). Examples include StereoMoms, to be flown in Spacelab in 1992 and later on in the Soviet MIR-Station, and the electro-optical scanner as part of the Japanese ERS-1 mission from 1992 onwards.

Independently there exist several initiatives to put *interferometric* radar to use. As part of EOS, the Jet Propulsion Laboratory is preparing a series of experiments to demonstrate how radar interferometry can automatically map elevations with an accuracy of 3m in every pixel of a radar image (Zebker and Goldstein, 1986). Similar developments exist at the Canada Centre for Remote Sensing (CCRS) and at the Environmental Research Institute of Michigan (ERIM).

6.3 Products of Softcopy Photogrammetry

With a wide range of sensors and a transition from mapping to the study of environmental phenomena by remote sensing, the products of photogrammetric efforts widen as well. This manifests itself in the need for new algorithms and sensor models, in the need for digital orthophotos, coregistered image cubes, image-based information systems and new, short-lived mapping documents describing position, direction of motion, change in properties of ephemeral objects such as ice, water, vegetation etc. Such new products could not be affordable, were it not for a high degree of automation to cope with current and anticipated daily quantities of image data. Only 10 years ago a national mapping institution would have been saturated for a year even with just one day's quantity in new remote sensing imagery.

7. OUTLOOK

We have attempted to show that the transition from film-based photogrammetry to the processing of pixel-arrays results in a dramatic change of tools, procedures, products and possibly also in a redefinition of the scientific foundation of the field. Once in digital image processing, the doors are wide open for a large variety of sensors and a broadening of the acceptance of photogrammetric operating principles in fields previously intimidated by photogrammetric equipment.

We need to realize, of course, that softcopy photogrammetry leads to three central changes:

* the cost of a system has the potential to be very low by just adding software to a standard personal computer with minimal attachments;

* the use of standard computers creates a perception of great value previously unavailable from single-use photogrammetric glass and metal;

* the transition of photogrammetry into some shrink-wrapped software much like a spreadsheet or word processing package removes the intimidating mystery of photgrammetry and leads to a democratization of photogrammetric technology.

Even *without* the benefits of automation there are already numerous advantages to softcopy photogrammetry that more traditional approaches cannot offer, and make photogrammetry available in new territories.

Of course, to sway the traditional photogrammetrist from the analytical plotter to the new softcopy technology will require that some clear advantages become evident in cost, throughput or accuracy in traditional tasks. These advantages are beginning to become confirmed as automation gets more developed. Doubling throughput is not an idle hope anymore when developing elevation models. Quality control gets dramatically improved and the digital orthophoto is rapidly finding acceptance through the GIS. Finally, one may fully expect that photogrammetry will become a standard complement to graphics computer workstations as digital images of natural objects become an accepted source of technical data.

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