DESIGN ALTERNATIVES FOR DIGITAL PHOTOGRAMMETRIC SYSTEMS

Franz W. Leberl
Vexcel Corporation, Boulder, Colorado, USA 80301

ABSTRACT

Conversion of the photogrammetric industry from film-based equipment and procedures for stereo- and orthophoto work to image processing work stations requires numerous design decisions to shape all elements of photogrammetric work. This paper reviews the options and suggests advantages and drawbacks of various such decisions.

The review can draw from the work presented and discussed by various authors and attendees at the 3 inter-congress events organized by ISPRS-Working Group II/III, as published in the collection of papers from these meetings (Dowman et al. (eds.), 1990; Leberl et al. (eds.), 1992; Ebner et al. (eds.), 1992). Specific design issues address the integration of the complete mapping process from imaging to the application of the data, the configuration of stereo and orthophoto systems, down to the details of computer operating systems, computer networking issues, stereo-cursor implementation, image management, softcopy image stereo viewing, graphics superposition etc.

1. INTRODUCTION

If one accepts the premise that the current transition from film-based to pixel-based photogrammetry is revolutionary, then one also must subscribe to the notion that photogrammetry's future is not easily forseeable.

As we move in small steps from a well-defined base into an uncertain future, decisions must be taken about the direction of these steps. During the course of the meetings of ISPRS Working Group II/III numerous observations were made about the way digital photogrammetric systems ought to operate. Many of these observations contradict one another. Obviously, the tumultous changes in photogrammetry leave room for many different views.

It is thus with considerable difficulty that we review design considerations for softcopy photogrammetric systems. There is no established base of academic literature, vendors are driven more by short term tactical necessities than strategic considerations, and users are still confused. However, we will in this paper present our view of design issues as they are seen at the moment. Since photogrammetry is a small field, its resources for innovation are small and cycles of innovation are slow. As the transition to digital systems takes shape, innovation becomes less a result of the field's internal forces than a by-product of developments in the larger computer industry.

This paper discusses first the overall mapping process and the forces that shape change there. Photogrammetric systems are then seen as a component in this larger process. Design considerations for this component of the mapping system take up the remainder of the paper

2. PHOTOGRAMMETRY AS A COMPONENT OF THE MAPPING PROCESS

2.1 The GIS: from Mapping to Built-in Map Updating

The traditional mapping process consists of

planning,
imaging,
control point positioning,
control densification,
photogrammetric data collection,
orthophoto-production,
cartographic visualization and
reproduction (Figure 1).

The user of mapping results was completely separated from the mapping process. The closest link ever established was in the event where orthophotos were being used and the user therefore was required to interpret the image, rather than to simply receive an interpreted and symbolized mapping product. The issue of editing an already existing map was addressed by a variant of the basic mapping process which again went "open loop" from the photogrammetric process to the user.

The most significant ongoing change may well be the fact that the user is beginning to get into the mapping process, since the Geographic Information System (GIS) presents urgent demands on current mapping data, with an ability and need to integrate the photogrammetric process into the end-user's GIS, rather than leaving it in the realm of the photogrammetric specialist.

At the highest level, therefore, the open-loop photogrammteric mapping process is being changed into a *closed-loop* involving the GIS user and making provisions for built-in updating of mapping products. A version of the photogrammetric system is being integrated into the GIS-process, resulting in GIS-photogrammetry (Leberl, 1991).

2.2 Surveying of Ground Control, and Control Densification

The Global Positioning System (GPS) is capable of instantly creating 3-dimensional control point coordinates. It thereby makes the considerations of "planimetric" and separate "height" control points obsolete. The manner in which GPS surveys are made from vehicles may also invalidate the issue of spacing ground control points as widely as is acceptable.

More importantly, kinematic GPS promises to position the camera platform with cm-accuracy, and interferometric GPS may add the attitude angles sufficiently accurately to remove the need for ground control points alltogether. The core of photogrammetric technology always was the control point densification; this would in this manner be replaced by direct GPS-based measurements.

A current alternative to "no control densification" is the full automation of the aerotriangulation process, as proposed in the DCCS-product (Miller et al., 1992). However, this still needs surveyed ground control points as input, whereas kinematic interferometric GPS would do away with all point positioning needs.
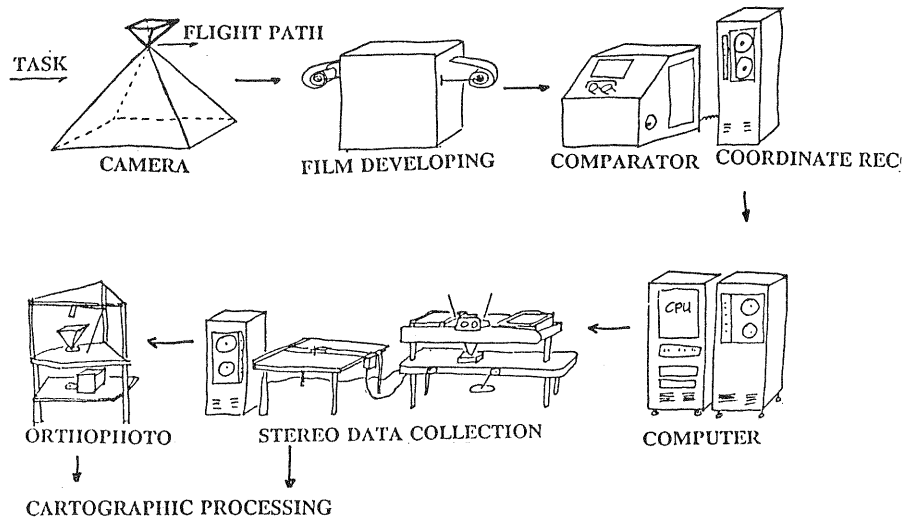
TASK → FLIGHT PATH / CAMERA → FILM DEVELOPING → COMPARATOR COORDINATE REC

ORTHOPHOTO ← STEREO DATA COLLECTION ← COMPUTER

ORTHOPHOTO ↓   STEREO DATA COLLECTION ↓

CARTOGRAPHIC PROCESSING

Figure 1: Traditional process flow through a photogrammetric mapping project.

2.3 On-Line Map Data Visualization: Merging Disparate Data Formats

The traditional separation of the mapping process into photogrammetric data collection and cartographic data presentation is currently being affected by the GIS. Instead of the two- step process, a single step is emerging that considers the cartographic data presentation in terms of computer graphics visualization. As this computer-aided process gets better defined, for example in systems such as Intergraph's MGE, data extraction (by photogrammetry) and data presentation (by cartography) merge into a single mapping tool box.

Most important in this development is the combined use of stereo imagery and GIS data at a mapping workstation. Instead of the disparate traditional formats of photographic material, pencil map manuscripts, artistically refined map separates and final printed color map, we can now plan on merging digital image raster files with individual GIS data layers or with a complete symbolized color visualization. Clearly this dramatically changes the overall process for creating -- and updating -- maps.

2.4 Sensing

The neglect suffered by digital satellite and aircraft images from the hands of the photogrammetric mapping process is rapidly ending. The GIS has shown to also be the driving force behind *this* development, which finds valuable uses of satellite remote sensing data, and more recently some aircraft digital imagery, in the creation of maps, in updating of existing maps, or simply by providing an image background for conventional GIS map data.

This development is not a result of discovering that certain mapping products do no longer need the high geometric resolution of photographic source imagery; it is rather a result of the need to very rapidly updating maps at very low cost for the source material. At presentation scales of 5 pixels per millimeter to an unaided eye, satellite remote sensing data with 10 m pixels are useful at a scale of 1:50,000, at 5 m pixel size, at a scale of 1:25,000.

Digital remote sensing images are available at resolutions of 2 m, for example as aircraft imaging radar data; at 5 m from Russian space photography, and at 10 m from SPOT.

The need to maintain high geometric resolution and accuracy will continue to be satisfied by aerial or industrial film photography. Therefore the photogrammetric mapping process will be augmented by the new tool of a photogrammetric precision film scanner. And it must be capable of processing various source images into standard mapping products.

2.5 The Digital Photogrammetric Process

The result of the ongoing changes in image-processing-based photogrammetry is a process as shown in Figure 2: control-point free image data and sensor position/attitude recordings flow into a one-step workstation. Results of data analysis go into magnetic storage such as a disk farm.

3. HOW MANY COMPUTERS PER PHOTOGRAMMETRIC WORK STATION?

A basic design question for the new digitial photogrammetric tools relates to the manner in which data are being presented and managed. In the past, cost enforced a thinking which related one computer to many users; this was followed by a thinking that related the two one-on-one. This is no longer necessary or useful. Computing cost has become low enough so that productivity may be higher with one high-cost user employing several low-cost computers simultaneously, rather than working with only one computer.

This is reflected in Figure 3 which suggests a *multi-headed* system for photogrammetric processing, with separate subsystems as follows:

* the Graphical User Interface and overall system control;

* the stereo image presentation;

* the GIS or Computer-Aided Design presentation;

* the film scanning element.

In this suggested arrangement 4 computers and three monitors would be available to the single user. The computers are linked in a local area network, and may be further networked with other users.

While Figure 3 may seem excessive, it illustrates a concept:

photogrammetry has always been a combination of "third party" elements, traditionally of mathematics, optics, mechanics, electronics etc.;
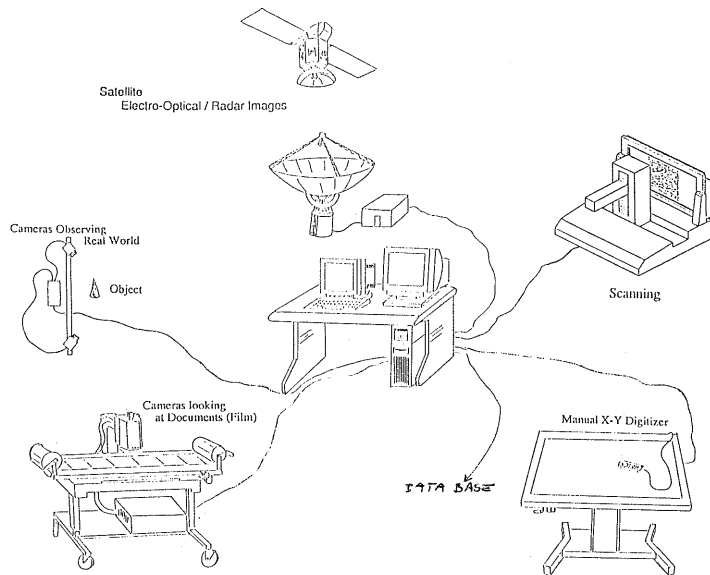
385

Figure 2: The digital photogrammetric process will be based on digital images or digitized photography. This will be complimented by precise kinematic sensor position and attitude measurements. Existing map data will be incorporated and analysis output will go into a Geographic Information System.

in the softcopy world, photogrammetry is also the beneficiary of multiple third-party subsystems, such as GIS/CAD, scanning, stereo-viewing etc.

the strict adherence to standards, and avoidance or minimization of specialized solutions, is very important in the rapidly changing computer industry.

It appears therefore reasonable to plan on the photogrammetric work station as an "instrument panel" which operates a diversity of computers. In this manner, the photogrammetry-unrelated and possibly rapid innovation cycles in sensing, GIS, CAD, computers and display technologies do not unduly stress the much smaller resources of photogrammetric innovation.

4. DATA VOLUMES

What quantities of data does a photogrammetric work station have to cope with? This has to be separated into several sub-questions:

* what data quantities need to be available in the instantaneous field of view?

* what data quantities pertain to a single photogrammetric session?

* what data quantities comprise a photogrammetric project?

4.1 Pixels Versus Line Pairs

The data content of a single aerial photograph is often expressed by the resolution in line-pairs per millimeter. Good quality photography is obtained with perhaps 30 to 40 lp/mm; with forward motion compensation, such resolution is said to improve to perhaps as much as 60 lp/mm (Meier, 1984). How many pixels are needed to resolve this type of film?

If one were to deal with binary data, i.e. black lines on a white background and 1-bit pixels, then the answer to this question is 2.8 pixels per line pair, or a pixel size p (in μm) deriving from n lp/mm as follows:

$$p = 1000/(2.8*n). \tag{1}$$

The answer to the question is much more complex than this simplified response, since pixels contain 8 bits (see Hempenius et al., 1986), a modulation transfer function approach leads to the need of even more pixels (3.3 per line-pair, see Makaroviac et al., 1979), and positional accuracy of a target is also affected by pixel size (Trinder, 1987, 1989). However, existing work does not support an unambiguous answer. Therefore it is a safe assumption to rely on equation (1). This suggests then that film at a resolution of 35 lp/mm be resolved onto pixels with a diameter of 10 μm, creating a data quantity of 23,000 x 23,000 pixels per photograph, or 529 MByte.

A stereo pair would be presented as 1 GByte at full resolution. A block of photography with 100 exposures would consume 50 GBytes.

4.2 Display Monitor

The stereo operator on an analytical plotter is familiar with a certain field of view and stereo viewing comfort. In the workstation environment the stereo display typically is capable of presenting 1,000 x 1,000 pixels of two images. At a resolution of 10 μm per pixel, this would represent a film area of 1 cm x 1 cm. If one agrees that 5 pixels should fill 1 mm on the display screen, then the 1k x 1k pixels would cover 20 cm x 20 cm.

A second concern is not only the area which is viewable, but also the ability to point in a single image with the help of a cursor, or to perform subpixel measurements with a cursor. This capability is available if a flexible local zoom-function is implemented to enlarge the image but not the cursor. For stereo imagery a subpixel measurement capability may require that either both images are locally enlarged, or that an image match take place to refine the cursor position to a subpixel accuracy.
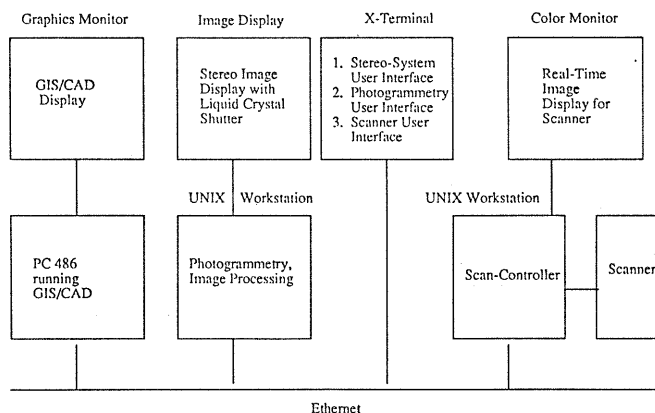
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Figure 3: Multi-headed photogrammetric working environment based on standardized software components (from Leberl, 1991; 1992).

A third concern is the presentation of the user interface and the imagery. To enable the use of standards it might be advisable to keep a graphical user interface (GUI) on a separate monitor, for example, employing the X-Windows standard. If the stereo image and the user interface were to be kept on the same display monitor, then the user interface could either not employ an established standard or the standard would have to be adjusted to accommodate the requirements of stereo image viewing and sub-pixel stereo mensuration.

4.3 Access to Large Data Sets

The analogy to the analytical plotter would suggest that the entire digital image pair must be available to the user in "real time". This could be translated into a roaming function that would move the 1K x 1K display window within one second from one end of the stereo model to the other. This would require a transfer of 1,000 x 23,000 pixels in each image, or a transfer rate of 40 Megabytes per second.

While this performance may be desirable, it will not be necessary. The roaming through the entire image data set can be accomplished in a multitude of ways which can be based on transfer rates that would refresh a 1K x 1K display window in perhaps half a second. This of course then would reduce the requirements on transfer rates to 2 Mb per second.

One may consider access to multiple photographs constituting an entire mapping project. In the event that 100 photographs need to be available at the full resolution of 10 m per photograph, one needs access to 50 Gigabytes. This is feasible with a jukebox arrangement of optical disks. Current transfer rates of a file of 500 Megabytes from a jukebox of optical disks may take several seconds. Access time in the analytical plotter to a new pair of photographs is about 5 minutes; the access time of seconds using a CD in a digital domain appears to be significantly faster, and no inner orientation is needed to "set-up" the stereo-model.

5. ORTHOPHOTO SYSTEMS VERSUS STEREO SYSTEMS

The initial application of digital photogrammetic systems is for the creation of orthophotos, not for the interactive extraction of stereo measurements. This is a reflection of the difficulty in effectively dealing with large stereo data sets in an interactive mode.

Digital orthophoto creation is intuitively appealing. The process does not require interaction with the image but can be implemented as a batch process. There is a scanning operation to decompose the original photograph into small image elements, and a second scanning motion to project those image elements onto the orthophoto. This traditional scanning process for orthophoto projection is also needed in a digital domain. However, the demands on scanning are comparatively relaxed when related to requirements for accurate stereo measurements. After all, the digitization of the photograph is merely for visualization of the result at graphical accuracy (to 0.5 mm) and for visual inspection with the unaided eye at 5 to 10 pixels per mm. At the presentation scale, the pixel size therefore would have to be 100 to 200 micrometers and the positional accuracy would be satisfactory, again at presentation scale only, at 200 to 500 micrometers. If an orthophoto is at 5 times enlargement of the original photography, then the resolution and accuracy numbers are:

pixel size of 20 to 40 micrometers,
accuracy of 20 to 40 micrometers.

This can be accomplished without need for innovation towards precise photogrammetric scanning.

A digital interactive stereo workstation presents an entirely different set of issues. This includes

the interaction with large images,
rapid access to individual windows and larger data sets,
the ability to measure stereoscopically,
subpixel placement of the cursor,
graphic super position,
real-time sensor modeling.

The orthophoto production is consistent with traditional image processing tools. Digital stereo workstations are an issue of graphical user interfaces, data management and rapid data access technology which are more complex to achieve with current digital tools.

6. STEREO VIEWING MODES

6.1 Polarization Versus Anaglyphic Viewing

The digital environment typically supports stereo viewing by displaying two images sequentially with different polarizations and the viewing with the help of polarized glasses so that each eye only has access to either horizontally or vertically polarized images. The alternative is the presentation of the two images in red and green colors using anaglyphic glasses to separate the two colors for viewing. The second concept is less useful because it prevents one from the display of color stereo images and use of color in the graphic super-position. In addition, the contrast gets vastly reduced, since light is being absorbed by red and green filters.

6.2 Data Organization and Parallax Removal

The presentation of two images is commonly accomplished by

an analogy to the stereoscope with a "frozen" image window and a moving stereo cursor,

an analogy to the analytical plotter with a frozen measuring mark and moving images,

or a combination of the two.

The demands on rapid data access and interactive roaming are much reduced if the display window is frozen and the cursor is moving over the window. Removal of any non-stereo Y-parallax is accomplished by warping the two images into an epi-polar coordinate system. Another approach is to shift the two images vertically with respect to one another as a function of the location of the stereo cursor.

The concept of a frozen cursor and a dynamic stereo window is attractive because it mimics the analog film world on the analytical plotter. However, real-time roaming is still not feasible without considerable expense for specialized image processing boards. The acceptance of digital technology may require that initially the images move dynamically and the cursor be fixed as it is in analytical plotters with binocular viewing. However, the penalty consists not only of costs, but also of a lack of portability of the software into other computer platforms.

A compromise between those two positions is the combination of a roaming cursor and dynamic roaming of the stereo window. Because of the motion of the cursor, the demands on the roaming of the image window are reduced. However, as computer technology improves, the roaming of the image window may improve with it and the option then exists to operate in a stereoscopic or analytical plotter mode using still the same software on various platforms at the speed that those platforms support.

6.3 Subpixel Stereo Measurement

As discussed previously, the requirement exists to point to a surface point in the stereo model with subpixel accuracy. This is typically not supported by hardware on standard computer workstations. Therefore some specialized software is needed which (a) locally permits to zoom in on an image window without enlarging the cursor, and (b) performs stereo correlation to interpolate a subpixel image match.

7. WHAT IS AN OPEN SYSTEM?

With the transition to digital photogrammetry, the innovation is taken away from photogrammetric industry and replaced by that in the computer industry as a whole. As a result, the photogrammetric capability is an application's add-on to existing computer technology by software and systems integration. Since photogrammetry is a small field, the resources for innovation are limited and the need exists to migrate with the photogrammetric application solution from the current computer technology to rapidly changing new digital products. This can be accomplished if one separates carefully the photogrammetric application software from the standard computer components. The most careful separation will result in an "open system" where the application software can be executed on a sequence of different computer platforms and employ various peripherals as they become available and migrate with the innovations in the computer industry.

We believe that the strict adherence to an open system philosophy is necessary for photogrammetry to reduce the cost and keep the investment in the photogrammatic application solution viable, even as the computer industry goes through a complete innovation cycle each three years.

8. UNIX VERSUS MS-DOS

Considerable debate exists in photogrammatic circles about relative advantages of personal computers operating with the MS-DOS operating system versus RISC workstations operating under UNIX. The considerations of a trade-off between these two approaches should be based on the concept of an open system. The operating system, which is available on personal computers and RISC workstations is UNIX. Given the demands on processing large data sets in an interactive stereo system, one may be more concerned with transfer rates within the computer system than with the cycle time of a particular CPU. Platform cost differences of RISC and PC systems are no longer significant. Therefore it will seem that the use of UNIX and RISC-type computers is advantageous.

9. CONCLUSION

The current rapid developments in all segments of the mapping field make it very difficult to orient oneself strategically in the photogrammetric segment of the field. The attempt in this paper is to review some of the core alternatives for the design of a digital photogrammetric system. We consider the environment in which photogrammetry operates and which is driven by the developments in the Geographic Information System. We are concerned about the use of standards and of an open system philosophy. As a result, we conclude that the photogrammetric workstation may consist of more than one computer to support the use of unmodified third-party software and to rely on standardized user interface technology.

We are concerned about the large data volumes resulting from digitization of aerial photography and the need to have rapid access in an interactive mode to arbitrary windows of imagery from a large database.

The major uncertainty about softcopy photogrammetric subsystems results from the rapid innovation cycles in computer technology and the comparatively limited resources available to innovate in photogrammetry at the same rate. Another major uncertainty results from the user community whose attitudes are mostly shaped by the Geographic Information System and the data requirements resulting from GIS applications. A shift from traditional long-term mapping programs at high accuracy to short-term database updating and monitoring functions can be observed and may change in unpredictable ways the manner in which photogrammetry is being used.

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