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PRACTICAL ISSUES IN SOFTCOPY PHOTOGRAMMETRIC SYSTEMS

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ABSTRACT

The transition is in full swing to abandon measuring methods using film images and replacing them by digital image processing. This development concerns every practitioner of photogrammetry. We will discuss some experiences with the new technologies and provide pointers through the maze of confusing observations and reports about the capabilities and limitations of digital photogrammetry.

We hope to show in a snapshot of the current situation that the technology works and that hardly an argument will hold up to avoid this new way of photogrammetric mapping.

1. INTRODUCTION

The analytical plotter was invented in 1958 (Helava, 1958). Yet it took until well into the 1980's to see the computer driven stereo measurements from film images to conquer every modern photogrammetric operation. Thus it took 25 years from demonstrating the analytical plotter until it had matured sufficiently for everyday acceptance. Today, of the perhaps 3500 to 5000 stereo instruments in operation on the globe, at least 1500 are analytical.

Softcopy photogrammetry, which in Europe is denoted as digital photogrammetry, has been demonstrated as part of military programs since the beginning of the 1980's (for example Case, 1982). Some may argue that academic research and planetary programs have preceded this by several years, producing fairly sophisticated stereo matchers (for example Haralick and Shapiro, 1993) and geocoded satellite or scanned film images, beginning with the first digital images from Mariner 4 (1964). However, we will argue that these developments were of components, not systems, and did not, in a systems sense, represent prototypes of photogrammetric work environments. Indeed, first actual photogrammetric softcopy systems were in all likelihood those described by Case (1982) and reviewed by Miller et al. (1992). The 1958-analytical-plotter-milestone can therefore be related to a 1982-softcopy-workstation-milestone. Does this then also mean that we must expect a 25-year period for this technology to become fully accepted, i.e. by about 2007?

No. Developments have accelerated, and innovation towards softcopy photogrammetry is driven not by photogrammetry, but by computer technology. Photogrammetry is merely "riding the coattails" of innovations made somewhere else.

It can be shown today that softcopy photogrammetry, if used competently, outperforms analog or analytical technologies. We will discuss some of the issues one needs to consider to actually accomplish a "competent operation".

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2. SOFTCOPY PHOTOGRAMMETRIC TASKS

The sequence of operations in a traditional photogrammetric system begins with sensing and the photolab, proceeds through point positioning via aerotriangulation to stereo-model operations for elevation modeling (DEM), orthophoto-production and stereo data collection for Geographic Information Systems (GIS). In a digital environment, the component processes are:

film scanning,

semi-automated aerotriangulation,

digital elevation modeling and orthophoto-production,

stereo data collection.

Only the orthophoto production exclusive of elevation modeling is currently a generally accepted domain for photogrammetric pixel processing. The other tasks are universally performed in the traditional manner using analytical or analog instrumentation.

The question is sometimes asked why one needs to bother with film at all: why can one not use digital cameras? For real-time and close range applications, this is actually happening. But for the photogrammetrist's bread and butter, namely aerial mapping, this is not an innovation that looks promising. Digital cameras to accomplish the functionality of aerial mapping cameras are not on the horizon. On one hand, such innovation would have to be driven by photogrammetric organizations since there hardly exists a broader application (unlike computers); and secondly, the technological challenge is enormous.: in a 1/1000 of a second, an aerial camera is capable of collecting the equivalent of 20 000 x 20 000 pixels, or 1.2 Gigabytes for a color image. Some may argue that the information corresponds to even more pixels.

Sensing technology for digital aerial applications could result from proposed space efforts, notably via recent US-commercial (for example Eyeglass, 1994) and German programs (Ackermann et al., 1991). In those cases, the cameras employ several long linear detector arrays at three locations in the focal plane of a high performance lens. However, the concept is far from mature and will, if ever proven advantageous over film cameras, totally invalidate the conventional wisdom of photogrammetric school books.

From a practitioner's viewpoint we need not dwell on digital sensing. Instead we will tour the photogrammetric process and comment on the softcopy versions of the process components.

3. PIXEL SIZE AND SCANNING

3.1 General Observations

There currently exists very little verifiable material for the relationship between pixel size and its effect on photogrammetric results. In principle we have the following requirements:

in *triangulation* we need to ensure that we extract point positions at an accuracy of perhaps ± 2 μm;

elevation modeling forces us to an accuracy of 7 to 15 μm at photo scale when matching two stereo images;

orthophotos need to present about 3 to 8 pixels per millimeter at display scale;

stereo *feature extraction* needs to support the full geometric resolution content of the source material to ensure that all relevant data are unambiguously identifiable.

The above numbers summarize the rules of thumb of traditional photogrammetry. How do they translate into pixel sizes and pixel positioning accuracies?

3.2 Triangulation

There is some evidence that centering on a symmetric target in a pixel array is independent of the target size, but depends on the pixel diameter (for example Almroth, 1995; Trinder 1987 and 1989). Accuracies are quite high, namely on the order of ± 0.05 pixels. As long as a triangulation effort is based on symmetric targets, the size of the pixels may not be an issue: they may remain fairly large, say in the range of 30 µm, yet they may result in good accuracies of $\pm$ 3 µm. This may change when the triangulation points are no longer symmetric but natural points, and when the triangulation is based on image matching for point transfers within strips and from one strip to the next.

However, there is little evidence in the literature which would clarify this concern. It is therefore unclear what the required pixel size should be to perform a triangulation with natural points and automated point transfer.

3.3 Stereo Matching for Elevation Extraction

Let us assume that we have used high resolution film with forward motion compensation, and therefore we want an elevation measurement to be very accurate, namely to within 1 part in 20000 of the camera constant (which amounts to 7 µm). For this we need a matching error of $\pm$ 0.6 * 7 µm = $\pm$ 4.2 µm (note a typical base-to-height ratio of 0.6). What should be the pixel size to obtain such an accuracy of matching? There exist no definitive studies to clarify this issue. One may speculate that matching will be accurate to within $\pm$ 0.5 pixels, provided that the object has good texture in the overlapping images at the pixel level. In this case the pixel size of 8.5 µm would appear to be sufficient.

Again the actual relationships are still in need of study.

3.4 Feature Extraction

Photo scale is usually determined either by elevation accuracy (often at large scales) or by identifiability of features (often at small scales). Photo scale is usually optimized and as small as permissible to economize on the number of photographs for a project. In the transition to pixels the qualitative contents of the photograph is at issue and needs to be fully represented in the digital domain. We may ask the question of the film's geometric resolution. This is typically expressed in terms of line pairs per millimeter, lp/mm, and ranges between 30 lp/mm for regular aerial imagery to 70 lp/mm for highest resolution obtained with forward motion compensation (Meier, 1984).

A measure for the pixel array's equivalent resolution is the subject of sampling theory, and is obtained by means of a modulation transfer function, by a so-called Nyquist frequency, or by the Kell-factor. Again, very little research exists which relates the information content of film images to the pixel size and the pixel's number of bits, i.e. its radiometric resolution. A limited effort was reported by Hempenius and Jia-Bin (1986) which clarified that the radiometric resolution is a determining factor in the geometric information transfer to a pixel array.

A safe assumption is the Kell-factor (Kell et al., 1940) which states that:

$$2.8 * p = 1000/n$$

with p as the pixel diameter in µm and n as the line pairs per millimeter. At 70 lp/mm the pixel size would have to be p = 5.1 µm.

This looks suspicious since we understand very well that the grain size in a photograph is often of the order of 10 µm or more. If furthermore we realize that grain itself is a binary information carrier, we must assume that the grain can be represented by 1-bit pixels; yet we employ 8-bit pixels.

We have put our finger on an unresolved issue. While we have various measures of resolution and rules such as MTF or Kell-factors, we obtain counter-intuitive results of pixel sizes that seem to be too small to be meaningful, given the grain size of photography.

Again the actual relationships between film type, number of bits per pixel and pixel size are in need of study.

3.5 Performance of a Scanner

Given the uncertainties that exist about the required pixel sizes of a scanning system, it seems that one should tend to the higher resolutions to have the options of addressing all requirements as they may exist in the various phases of photogrammetric work. Resolutions of 8.5 µm per pixel may not be exaggerated if a full range of capabilities is needed. This, in turn, would represent a measure of 3000 pixels per inch (dpi).

4. ABOUT SOFTCOPY TRIANGULATION

In the digital domain, triangulation offers capabilities that are non-existent in the film domain. These are mainly the following four:

- triangulation measurements can be automated and the triangulation throughput can be dramatically increased;

- through automated image matching one can, at no extra cost, employ multiple match points among images at each of the Gruber locations;

- point transfer can be accomplished with multiple images at hand, rather than using just pairs as is enforced by the two eyes of an operator;

- point transfer and triangulation computation can be combined into a single process.

As a result we not only may obtain a process that is much faster, say within a minute or two per photograph, but also much more robust and accurate.

However, we also need to note that this promise of softcopy triangulation is currently just A "promise". Actual systems that are automated, use multiple points in each Gruber location, perform the match and adjust the coordinates simultaneously do not exist. Studies and demonstrations of the concepts, however, do exist, for example in the work by Agouris et al. (1994) and Ackermann, Tsingas (1994).

These studies confirm the expectation that softcopy triangulation will outperform traditional analytical plotter methods: it will be twice as accurate and 5 times faster (Ackermann, Tsingas, 1994).

5. CREATING A DIGITAL ELEVATION MODEL

Elevation measurements have long been the major target of automation research. Analytical plotters have been equipped with cameras and video signals were matched. Generally, however, DEMs by automated image matching has never become an accepted technology. Only at rather small scales and over open terrain has image matching produced acceptable results. In other cases the manual editing of the match-results requires an effort which invalidates the assumed advantages of the matching process.

The situation has changed only little over the last few years. Therefore it has remained the preferred method to collect DEM data on an analytical plotter by following contours (the conservative approach) or by measuring point grids and supplementing them by points along terrain break lines. MATCH-T represents a DEM generating software system of as good a performance as can currently be expected (Ackermann and Schneider, 1992).

While there is slow progress towards advantageous DEM automation, the analytical plotter can be avoided. Manual measurements are also possible on a softcopy work station. The typical DEM creation will, however, begin with automation and end with manual editing of the contour lines or DEM point pattern.

There exists, however, a type of DEM that can routinely be produced by automation: this is the DEM used for orthophoto production only.

6. ORTHO PHOTOS

Orthophotos do not challenge the photogrammetric process. Essentially they are a graphical product for visual inspection. Therefore they need not be more accurate than the medium on which they are displayed. Also, orthophotos do simply fit their geometry with respect to a "bald Earth", that is, the vertical objects on top of the bald Earth remain geometrically distorted. Therefore orthophotos remain of limited geometric accuracy.

While the digital version of an orthophoto pixel array would offer the possibility of "fixing" these traditional orthophoto errors, there exist no commercial systems today that actually would correct vertical objects.

Traditionally orthophotos were to be enlarged by a factor not to exceed 10. This has to do with the sensitivity of the human eye which is capable of seeing about 3 to 8 pixels per millimeter. If the source image had 30 lp/mm, then a 10 times enlargement would have a resolution of 3 lp/mm, or 8 pixels per millimeter.

Many photogrammetrists use 30 μm pixels today if they scan a photograph for orthophoto production. At this resolution, the presentation at a 10 times magnification would present the user with 3 pixels per millimeter, which is marginal. Therefore the enlargement should either not be by a factor of 10, or the scan resolution would have to be higher.

All current softcopy systems for sale can produce digital orthophotos on a routine basis. This technology has also been fully accepted since the product -- the digital orthophoto -- can easily be integrated into a GIS as a backdrop.

However, to fully satisfy the expectations one can have the technology has yet to learn how to correct the geometry of vertical objects such as buildings or trees. Just as this capability is missing in the DEM arena, it is also missing in the orthophoto arena.

7. STEREO MAPPING

While numerous vendors and developers offer solutions to extract planimetric features from stereo photography, there is no acceptance by practitioners. Features are all still mapped on analog or analytical plotters. The obvious reason lies in the *perceived* lack of an advantage to collect map features from digital images, and therefore the lack of an economic justification to replace the existing analytical photogrammetric work stations.

This hesitation is further reinforced by various other issues. Most important is the concern about viewing fatigue and quality of the stereo image on a computer monitor. Of course there also exist doubts about the geometric accuracy.

As a practical matter, these concerns have so far not been conclusively dispelled. There exists the paradox that numerous vendors are offering stereo mapping software on very comfortable work stations, but that they cannot publish persuasive reports on productivity, mapping accuracy, throughput increases and operator fatigue.

Yet this lack of data and reports does not imply that there is good reason to abstain from softcopy work stations. There exist significant advantages in interactively tracing features on a stereo monitor, to enjoy the benefits of semi-automation in line following, semi-automation in stereo matching, automated quality control and graphical stereo superposition.

Of course today's vendors are somewhat guilty of premature product releases: automation in feature tracking is typically not part of the current systems. Yet they all seem to be preparing add-ons to offer such automation. They also are guilty of ignoring the users need for reliable and persuasive information about throughput advantages in feature collection.

At the current time, the "market" for stereo feature mapping on softcopy environments still needs to "be made".

8. CURRENT STATUS OF AUTOMATION

We already reviewed some elements of automation in photogrammetric softcopy environments. Let us take a closer look at where the developments stand at this time.

In *triangulation*, some initial news is very encouraging. A tight integration between the scanning process and the triangulation computations is desired to accomplish nearly complete automation:. Scanning from uncut rolls of negative film is combined with fiducial mark recognition, definition of tie points etc. This is in the process of development and may soon be in the hands of pilot customers. Automation is feasible and very "easy" to accomplish.

Elevation modeling has already been discussed above, and so has orthophoto production. A high degree of automation has bee accomplished in both areas. While there is no question about the acceptance of automated orthophoto production, there exist some limitations in the DEM production.

The automation of collecting *planimetric features* is the weak link in the softcopy process. Great opportunities exist to dramatically increase throughput by automation. Yet the current user must live with a softcopy analog of the analytical plotter and therefore cannot yet enjoy significant automation. Yet many advantages could be provided with only modest efforts. Vendors are called upon to implement some tools to support the human operator in collecting stereo map data. While throughput advantages are feasible even without much automation support, it will be automation that will persuade the common user that this technology has arrived to replace the analytical plotter.

9. IMAGE RECORDING

Today's digital images can be viewed on interactive high resolution computer monitors. However, there remains a need to put these images back onto paper or film, or so-called "hard copy". This can be accomplished without a photo laboratory since such data will be recorded onto paper or film directly and as a positive. Fortunately, there exist many consumers of image recording devices, far beyond the small group of photogrammetrists. Therefore we do see a rapid development of innovative technologies for high resolution film recorders at amazingly low cost.

These are the tools to render the photogrammetric photo lab obsolete. So-called "poster makers" permit one to create large format (48" by infinite) photographic output from digital image files, or smaller 11" x 17" hard copy color photographs, essentially in an instant. Capital equipment may be in the range of US$ 10 000, and material per image may run at US$ 1 to 10 per sheet, depending on speed or quality. Even color copiers are in the process of becoming of reasonable quality to output color photographs from digital files, at a cost of well below US$ 1 per sheet.

Color image recorders are thus a required tool for every photogrammetry shop.

10. THE FUTURE

Softcopy photogrammetry is operational. All photogrammetric tasks can now be performed in softcopy at a throughput and accuracy either better or at least equal to traditional analytical tools.

Someone starting a photogrammetric operation today would be ill advised to invest into anything else than softcopy photogrammetric environments. Someone already operating with traditional analog or analytical equipment is tempted to wait to better understand the cost/benefit ratios of the new processes as compared to the traditional ways. These advantages are abundantly evident in the case of triangulation, but they are not yet widely being offered as products.

The advantages are also entirely transparent in the production of orthophotos, and a large number of vendors make this the first fully accepted component of softcopy photogrammetry.

In DEM production and in the collection of planimetric map and plan data, the advantages exist also, but they have not been made transparent to the community in a persuasive and conclusive manner. It will be task for the innovators in the field to produce the convincing evidence of the advantages of softcopy photogrammetric DEM and planimetric data collection, and will also be a task to improve these advantages by means of automation.

11. CONCLUSIONS

We have discussed the four phases of photogrammetric operations, namely triangulation, elevation mapping, orthophoto generation and planimetric feature mapping. We have commented on the current state of affairs regarding their implementation and use in a softcopy photogrammetric environment. And we have shed some light on the scanning of film images into digital pixel arrays, with some considerations of the required pixel sizes. We conclude that scanning must be available at fairly small pixel sizes of perhaps 8.5 μm to cover all applications of photogrammetric images.

Many of the issues of softcopy photogrammetry remain unclear. The cost/benefit ratios of a softcopy system versus a traditional system must be studied at many locations so that a persuasive and convincing body of evidence gets created. This will remove the obstacles in the minds of the concerned consumers of photogrammetric technology against making the commitment to embark fully on a digital-only system of operations.

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