A SYSTEM CONCEPT FOR DIGITAL ORTHOPHOTO GENERATION

R.Arbiol
I.Colomina
J.Torres

Institut Cartogràfic de Catalunya

Presented paper to the

Intercommission Conference
on
FAST PROCESSING OF PHOTOGRAMMETRIC DATA
2.6.87-4.6.87
Interlaken

A SYSTEM CONCEPT FOR DIGITAL ORTHOPHOTO GENERATION

R.Arbiol
I.Colomina
J.Torres
Institut Cartogràfic de Catalunya
Balmes, 209-211
08006 Barcelona
Catalonia-Spain

ABSTRACT

It is becoming apparent that in the future, systems for digital orthophoto generation (DOG) will be part of more general digital photogrammetric systems (DPS) which will already incorporate all the hardware elements and the software environment required for DOG.

Although the basic process of DOG can be performed in general purpose computers, the integration of DOG in a DPS represents not only the use of a new technology to speed up a traditional process but the possibility to deliver a more controlled (quality) cartographic product. The basic components of the proposed concept are: interactive planning of the orthophoto project; interactive preparation of the rectification process (selection of images, mosaicking) and interactive quality control of the final product. Some single appealing features of this concept are: a priori estimates of accuracy for the final orthophoto; fully automatic inner orientation and no need for stereomodel resetting; comprehensive mathematical models to squeeze the potential photogrammetric accuracy; computer aided design of "contribution zones" (mosaicking); on-line quality control for geometric and radiometric coherence of mosaics, blunders in DTM data and overall geometric horizontal accuracy of the orthophoto.

The realization of this concept in the frame of a DPS only involves the development of software. Photogrammetric equipment tailored for orthophoto production will no longer be required thus allowing many organizations to produce orthophotos just by incorporating additional software to their systems.

The possibility of partial realization of this concept with current available hardware is evaluated. Tests on the feasibility of individual components of the system are given.

1 INTRODUCTION

During the last years some concepts about digital photogrammetric systems, which are becoming of general acceptance, have been proposed (Albertz et al. 1984, Gruen 1986, Sarjakoski 1981). According to many authors one of the salient features of a DPS is its "unique ability to master all photogrammetric and cartographic tasks of data processing, data editing, and partly of data acquisition" (Gruen 1986). In particular, this applies to the orthophoto generation: "on all accounts, a digital stereophotogrammetric system is more powerful than common instruments. A system designed for photogrammetric purposes will be capable to perform all functions of analog instruments such as rectifiers, comparators, stereoplotters, dodging instruments or orthophoto projectors" (Albertz et al. 1984, p.7).

On one hand, such general DPS are still a matter of investigation. Moreover, "the design of a universal photogrammetric digital image processing system represents a difficult and expensive long-term task" (Jaksic 1984).

On the other hand, just for pictorial-to-pictorial conversions where no planimetric feature interpretation has to be done the digital approach appears to be readily applicable (Wiesel 1985, Gaydos et al. 1986). Moreover, it should not be overlooked that national DTM data bases will be completed before least squares correlation for DTM generation becomes common practice. Therefore, the development of systems for DOG seems to be justified in the next 5-7 years.

That is the situation in our Institute, where a DTM data base is being collected as a byproduct of an orthophoto project supported by a Gestalt Photomapper (Alberich 1985). This DTM allows for DOG through digital image rectification (DIR) (Arbiol et al. 1987). The ICC is interested in the design of a system for DOG to support the continous product update when the project is finished or simply the production when suitable DTM is available from any other source.

This transitory approach towards a universal DPS through the development of more or less dedicated DPSs to specific tasks seems to be realistic and it is shared by some manufacturers.

In spite of all the questions to be solved before the full realization of the DPS concept, it is worth to spend some effort thinking about "how a DPS will handle DOG". This is so because in the frame of a DPS new concepts and procedures can and shall be applied to the generation of orthophotos due to the availability of many more resorts. Afterwards, we can go back to our current hardware and software and try to implement as many as possible of those concepts.

A lot of discussion has been going on in our Institute about these ideas and we find out that it is possible, nowadays, to deliver a product which is more accurate (because of the use of comprehensive mathematical models), more controlled (because of the on-line quality control and on-line accuracy estimation), cheaper (because of the possibility to relax flight conditions via digital mosaicking techniques and the use of cheaper hardware), radiometrically better (because of the use of image processing procedures) and, last but not least, which is transferable through a cheaper, more stable and more flexible support (softcopies of orthophotos and stereomates).

Of course, subtle but nevertheless important features of a DPS will be gone if one acts carelessly. If the original analog image, for instance, has to be digitized each time it is needed the concept of a stable image over time with no need for repeated inner orientation is lost.

2 DEVELOPMENT OF THE CONCEPT

The main steps of the DOG process are data preparation, image rectification -i.e. DIR-, final mosaicking and quality control. Remaining non-photogrammetric steps such are the merging of contours, or the placement of names and symbols will not be considered in this paper.

The heart of a DOG system is the DIR subsystem, which repeatedly applies the perspective transformation to the DTM points and further interpolates this transformation for some additional points (figure 1). The DIR subsystem controls, as well, the distribution of "contribution zones" (1), that is, from what image are to be taken the grey values.

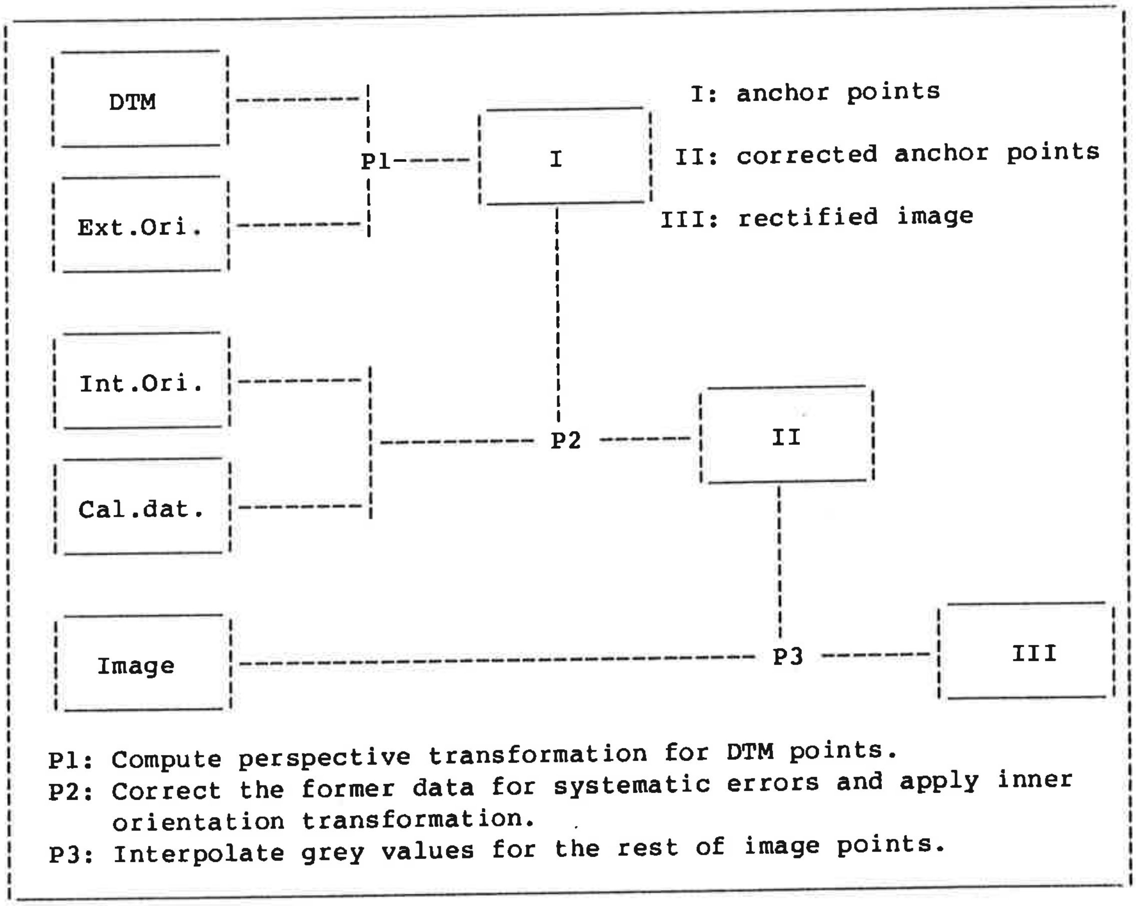

Figure 1: Scheme of DIR process.

The utilization of DIR for DOG, represents an important step towards better accuracy and more automation. However, this is not the only

---

(1) A "contribution zone" is characterized by the condition that all the points in it have to be rectified using the same image. We will refer to them as "patches" in the rest of the paper.

point. The flexible physical support where the digital orthophoto resides, the software environment, together with the available hardware components of a DPS opens a new field of possibilities to the orthophoto generation. Moreover, the rest of steps in DOG can be handled by a DPS thus eliminating some tedious manual operations. The whole process, from data acquisition to the final map, through DIR preparation, can be managed at the workstation.

Next, we review some facts and pose some questions which lead in a natural way to our system proposal.

GREAT VARIETY AND DISPARITY OF INPUT DATA. DTM data bases are becoming more and more available and therefore, it is possible to produce orthophotos from basically, any photogrammetric project. Traditional enlargement factors will be too conservative if FMC magazines are used and pixel size will have to be accomodated to the actual resolution. Making the right decision in front of this variety of data when planning the orthophoto mapping project might result difficult. Focal lenght, image scale and image overlap strongly depend on the precision of DTM data, exterior and interior orientation elements, and image resolution. It is therefore, useful, having a PREANALYSIS SUBSYSTEM which is capable of predicting the accuracy of the orthophoto. The subsystem is thus a tool for both project design and feasibility checking for a given set of data.

INTENSIVE USE OF IMAGE PROCESSING TECHNIQUES FOR MOSAICKING. Digital mosaicking allows for greater flexibility in flight design. Again, practically any photogrammetric flight can be used for orthophoto generation. The counterpart is the need for careful design of patches: selection of images and definition of mosaic seams. Then, the next question arises: is it still necessary, or even possible, to prepare the rectification in the traditional way (flight "index", checking through positive copies,...) ? A PREPARATION SUBSYSTEM has to be considered which with the help of the DTM, graphic and image processing subsystems, embodies the following functionalities: display of image projection centers, contours and map frames and display of the images (which could be resampled work-images at 200-300 mu).

With this facilities the selection of images can be done and a first definition (coarse) of mosaic seams can be made. It might be also considered the possibility of injecting contours and map frames into the images. The definition of the seams could be aided by algorithms which detect linear natural features.

NEED FOR QUALITY CONTROL. There are several potential error sources in the generation of a digital orthophoto. Some of the most frequents are: geometric incoherence of mosaics; radiometric incoherence of mosaics and gross deformations of the image due to blunders in DTM data bases (mainly due to the obsolescence of elevation data). The need for quality control comes, as well, from the wide range of applications of a digital orthophoto which, essentially, has no scale. For users of softcopies (for instance, if the orthophoto has to be added as a layer to a Geographic Information System) realistic estimates of horizontal accuracy will be of most interest.

We grouped the verification tasks in three items: mosaic quality control; DTM quality control and horizontal quality control.

For the first group a visual inspection is enough. For the second group (DTM blunders) and following the ideas of Ebner et al. (1987), several strategies might be useful: stereoscopic inspection of the orthopho by means of a digital stereomate; superimposition of contours in t orthophoto; and finally their combination. Also the difference betwe the orthophotos generated with different adjacent images might considered.

For the third group (horizontal accuracy) the usual way to do it is t identification of a number of check points in the orthophoto a comparison of their coordinates with the "true" values. This is nuisance for an analog orthophoto, even if the true values are obtain photogrammetrically. In the frame of a DPS, and if an image correlati subsystem is available, accuracy estimates for the orthophoto can b computed easily: take some uniformly distributed points (i.e. patche in the orthophoto, correlate them to their homologous points in th images, and use a photogrammetric subsystem to get their coordinate One can even determine the check-coordinates simultaneously to th correlation (Gruen et al. 1986). No problem has to be expected her from the correlation since there are good initial approximations for al the parameters and the number of points is small so there will be n excessive computational load. Finally, if a would-be-check-point fail to be correlated, it can be just rejected and substituted by another Of course, the accuracy estimates are "local" in the sense that th exterior orientation elements used in both quality control an rectification operations are the same.

These considerations lead us to the inclusion of an ANALYSIS SUBSYSTE with the following functionalities: display of the orthophoto (ideally with panning and zooming facilities); display of the orthophoto an superimposed contours (idem.); stereoscopic display of the orthophot and the stereomate; and estimation of horizontal accuracy.

In addition to these just proposed three subsystems there are the DIF and MOSAICKING SUBSYSTEMS with obvious tasks. A summary of the components of the DOG system is outlined in figure 2.

3 DOG SUBSYSTEMS

The purpose of this section is to describe more in detail the five DOG subsystems.

3.1 PREANALYSIS SUBSYTEM

The preanalysis subsystem is in charge of error simulation for project design and of error prediction for already existing data. It computes horizontal standard errors for a grid, or selected points, within the limits of the orthophoto. The usual information for this kind of computations is then given: average error, maximum error,etc.

Input data are the limits of the orthophoto, and data for the simulated rectification and their assumed or known standard errors. Then, by application of the error propagation laws, the horizontal standard errors of the orthophoto are obtained.

A batch prototype has been developed. After many work sessions it was apparent that this kind of analysis should be performed under a graphic menu driven environment which allows for easy manipulation of the input parameters and graphic display of the results.

The error propagation routines are conceived as part of the photogrammetric subsystem (PS). The preanalysis subsystem uses, then, the graphic and photogrammetric subsystems and the network, elevation and frame databases (figure 2).

DOG system / DPS	IP	GS	PS	DS	CS	Data Bases	ND	ED	ID	FD
PRAS		--	--				--	--		--
PRES	--	--	--	--			--	--	--	--
DIRS					--		--	--	--	--
MOSS	--	--								--
ANAS	--	--	--	--	--		--	--	--	--
Acquisition System										
SCAS									--	
SCCS					--		--		--	
INMS	--				--		--		--	

ENVIRONMENT SUBSYSTEMS:

IS: image processing subsystem.
GS: graphic subsystem.
PS: photogrammetric subsystem.
DS: DTM subsystem.
CS: correlation subsystem.

ACQUISITION SUBSYSTEMS:

SCAS: scanning subsystem.
SCCS: scanner calibration subsystem.
INMS: image input and management subsystem.

DOG SUBSYSTEMS:

PRAS: preanalysis subsystem.
PRES: preparation subsystem.
DIRS: DIR subsystem.
MOSS: mosaicking subsystem.
ANAS: analysis subsystem.

DATA BASES:

ND: photogrammetric network.
ED: elevation (DTM) data base.
ID: image data base.
FD: frame data base.

Figure 2: DOG subsystems and DPS subsystems.

3.2 PREPARATION SUBSYSTEM

This subsystem is required because of the intensive expected use of mosaicking. The final mosaic has to be done after rectification, when the final seams can be exactly defined. The task of the subsystem is to define rough seams and, if mosaicking is not necessary, at least to select the image to be used for each orthophoto.

In a first step, the contours for the whole area covered by the project, map frames and projection centers are displayed. Some images will have been already selected by the subsystem as the best candidates (usually, the central image). At this point, he can just digitize a seam or, if more information is required, display any of the work images (digitized at 200-300 mu) with or without contours superimposed for closer inspection. The seams can be either digitized in the map reference system or in the image. Ideally the subsystem should allow for stereoscopic inspection of stereopairs but this last point seems to be not critical if contours are superimposed to the images (after due perspective transformation). The output data of the preparation subsystem are, essentially, polygons in the map or in the image space which are attached to particular images.

The subsystem uses as ancillary subsystems the graphic, DTM, image processing and photogrammetric ones and accesses all the data bases.

3.3 DIR SUBSYSTEM.

As it is shown in figure 1 the rectification process can be splitted into three more elemental subprocesses. The intermediate transformation (P2) can be avoided if a resampling of the original digital image to reduce it to the strict perspective model has been done.

If the exterior orientation elements are known, DIR is a batch process. Even if the "on-line" approach is used (Wiesel 1987), i.e. the digital image is not stored but digitized simoultaneously to the interpolation of the grey values, a significant part of the computations (P1 in figure 1) can be performed prior to the actual orthophoto generation.

The DIR subsystem proceeds to the rectification of the images according to the results of the preparation. This is a typical flow: request for a digital image if it is not stored in the workstation disk; perform automatic inner orientation if necessary; compute anchor points; interpolate grey values and produce the digital orthophoto. The equalization of the patches to be rectified is done, as well, during the DIR batch session.

Contrary to the preanalysis and preparation subsystems, the rectification runs in batch mode. A typical situation would be something like this: the operator starts his job by analyzing the orthophotos ordered in a previous session and defining the final seams of the mosaics; afterwards he prepares the rectification of a new lot and submits it to the DIR batch process.

3.4 MOSAICKING SUBSYSTEM

This is standard image processing application software.

The already rectified and equalized patches overlap each other so the operator has a certain degree of freedom to define the final seam. The coarse seams digitized during the preparation session together with the actual borders of the patches can be superimposed to easy the operator's task. This is the first step -interactive- of the mosaic generation. Once the final seams are defined a second -batch- step is required for masking and final mosaicking.

3.5 ANALYSIS SUBSYSTEM

Rather than a preestablished sequence of tests and inspections this subsystem is a collection of verification tools that the operator has to use according to his experience and the kind of data. Basically, there are three aspects of the orthophoto which have to be controlled: the mosaic, the DTM-image eventual mismatches and the metric accuracy.

For the mosaic verification, a visual inspection of the orthophoto is enough. The seams defined in a mosaicking session will be optionally superimposed to the orthophoto in order to help the operator in searching eventual image discontinuities.

Another point is the possibility of gross deformations in the orthophoto because of variations of the terrain for which the DTM data base was not updated. We note here, that this is not a procedure for the maintenance of the DTM data base, but just to prevent from non incorporated modifications. The experiences from our current orthophoto project indicate that this kind of verification relies on the photointerpretation of the orthophoto image plus 3D information given by the DTM. The simplest approach is to superimpose the contours to the orthophoto. More sophisticated approaches are the generation of a digital stereo-ortophoto, that is the orthophoto and its stereomate, which allows for a faster inspection. Another possibility is to produce the orthophoto twice, each time using a different input image. Then, the two orthophotos can be substracted pixel by pixel, and the resulting ortho-diference can be displayed to quickly detect eventual large deformations.

Finally, as mentioned in the previous section, there is the possibility to estimate the horizontal accuracy by means of image correlation and, of course, by means of check-points when available.

The analysis subsystem requires all the environment subsystems and data bases and, together with the preparation subsystem, are the more complex and demanding subsystem, both from the hardware and the software points of view.

4 TESTING THE CONCEPT

Our Institute has started the concept validation phase by checking the feasibility and performance of every single component of the subsystems. So far, some of them have undergone preliminary testing and the results will be given in this section. For this purpose, two aerial photographs at 1:22000 scale were digitized at 50 mu and 22.7 mu (1) pixel size, and two digital elevation models were compiled. The first one was compiled at the Gestalt Photommaper IV (GPM-IV) of our Institute. The second one was compiled photogrammetrically. The digitization of the images at 50 mu was done with a drum scanner. The digitization of the images at 22.7 mu was done at the GPM-IV. In order to check the scanner a grid plate

---

(1) At the ICC the GPM-IV was modified by adding and analog-to-digital converter which allows to output pixels on tape. This work has been reported in an internal document (Fernàndez 1986) and since its set up we obtain digital orthophotos from the Gestalt. Our modified GPM-IV can thus be used as a scanner.

was also digitized (only for the GPM-IV). Finally, and "obsolete" DTM was generated in the neighborhood of a highway, to simulate a public work for which the DTM has not been updated after the construction of the highway. A summary of the characteristics of input and test data is given in figures 3 and 4.

```
2.3 * 2.3 Km2

average height       :  301 m        maximum height:  354 m
maximum height diff.:  127 m        minimum height:  227 m

DTM 1: GPM-IV.                      DTM 2: stereo-comparator.

        RMSZ:     1.77 m                    RMSZ:     0.80 m
        Interval: 3.9 m                     Interval:  15 m

Situation of the check points within the image (units are in mm
and referred to PPS).

        min X:   -91        max X:   27
        min Y:   -60        max Y:   51
```

Figure 3 : characteristics of the test DTMs.

```
Image 5098     Camera: Wild RC-10      Focal lenght: 153.26 mm

Case 1 (drum scanner)                 Case 2 (GPM-IV)

pi: 50 mu                             pi: 22.7 mu
scanner precision: not tested         scanner precision: 11 mu

Precision of interior orientation elements (affine trans.):

Sx : 0.12 pi : 6 mu                   Sx : 0.18 pi : 4 mu
Sy : 0.12 pi : 6 mu                   Sy : 0.18 pi : 4 mu
Sa : 5.7E-5 (same for Sb,Sc,Sd)       Sa : 3.6E-5 (same for Sb,Sc,Sd)

Precision of exterior orientation elements (from bundle adj.):

Sx : 0.50 m     Sy : 0.36 m      Sz : 0.16 m
Sw : 64   cs    Sp : 96   cs     Sk : 25   cs      1 cs : 1E-4 gon
```

Figure 4 : precision of input data.

The following subsystems were checked: the prototype of the preanalysis subsystem, The DIR subsystem (accuracy of the orthophoto), the mosaicking subsystem (for radiometric coherence) and the analysis subsystem (superimposition of contours in the orthophoto, generation of an orthophoto and its stereomate using the obsolete DTM and the substraction of the orthophotos). Last, the feasibility of a scanner calibration subsystem was also tested (automatic measurement of reseau crosses) succesfully.

The metric and related tests were based on a set of 62 points uniformly distributed all over the orthophoto, which were compiled at the analytical stereo comparator Wild AC-1. They were artificially marked in both images with the Wild PUG-4 point transfer device.

4.1 TESTING THE DIR SUBSYSTEM

Apart from the computing time, three questions were tested for the batch DIR subsystem: ability to locate without operator intervention the fiducials; geometric horizontal accuracy and radiometric coherence of the mosaic. We recall here, that the equalization of image histograms is carried out by the DIR subsystem although conceptually belongs to the mosaic process.

No problem was detected for the automatic localization and measurement of the fiducial marks (correlation with a syntetic template). The pointing accuracy (sigma naught of the inner orientation adjustment) was of 0.25 pi (12.5 mu) for the case 1 image and of 0.37 pi (8.4 mu) for case 2 (figure 4).

As for the horizontal accuracy two tests were performed. First, the Gestalt DTM and the image 1 case (figure 3) were used. The Gestalt DTM was previously treated by a numerical process to remove blunders occurred during correlation (Allam 1978, Arbiol et al. 1987). Due to the extrem high density of the Gestalt DTM only a subset of it was used for the rectification: 1 point out of 10, thus resulting in a square grid of 39.9 m interval. The size of the output pixel size was 1 m, i.e. about 45.5 mu at image scale. The results of this test are shown in figure 5.

Meters at ground scale	m	sd	rms	Microns at image scale	m	sd	rms
x	.00	.51	.51	x	0	23	23
y	-.11	.44	.45	y	-5	20	21

Figure 5 : results of the accuracy test (1).

A second accuracy test, this time with the DTM 2 and case 2 image (again, see figure 3) was made. The interval between grid points was 15 m and the output pixel size was 0.5 m, i.e. the same pixel size as the digital input image. Figure 6 summarizes the result of this test.

Meters at ground scale	m	sd	rms	Microns at image scale	m	sd	rms
x	-	-	.28	x	-	-	13
y	-	-	.42	y	-	-	19

Figure 6 : results of the accuracy test (2).

The numbers in figure 6 are only indicative (even pesimistic for the y component) since the poor quality of the GPM-IV digitization made difficult aiming at the pugged points. According to our standards this results allow us to use enlargement factors (just from the accuracy point of view) up to 4.4 for the Gestalt DTM, which means an orthophoto at 1:5000 scale. In the second case the maximun enlargement factor is 5.2, or equivalently an orthophoto scale of 1:4200.

Concerning the radiometric coherence of mosaics the test consisted in the generation of half an orthophoto with one image and the other half with the other image (both images belonging to case 1) and no noticeable discontinuity or radiometric difference was detected.

After these experiments the only real problems left for the DIR subsystem are the computing time and the storage needs which will be discussed in a next section.

4.2 TESTING THE PREANALYSIS SYSTEM

We tested the ability of the system to predict the metric accuracy of the orthophoto. For the testing, the propagated standard errors were not evaluated on a grid of regularly spaced points but just on the set of 62 check points.

The elements which mainly determine the precision of the orthophoto are the precision of exterior and interior orientation elements, the precision of the DTM and the precision of the scanner.

The precision of exterior orientation elements was obtained together with their values in the bundle adjustment, the precision of the interior orientation elements after the digital inner orientation (from nominal fiducial marks to measured fiducial marks in the grey matrix), and the precision of the DTM was obtained by comparison against the Z coordinate of the 62 check points.

Although we had figures for the precision of the GPM-IV scanner we did not use them for the error propagation, since we considered that the precision of the interior orientation elements absorved the errors of the scanner.

Figure 7 shows the results of this test.

DTM	Image	Predicted A	Predicted B	Measured
1	case 1	x : 38 mu y : 31 mu	x : 24 mu y : 18 mu	x : 23 mu y : 20 mu
2	case 2	x : 30 mu y : 26 mu	x : 11 mu y : 9 mu	x : 13 mu y : 19 mu

A : Standard error of ext. orientation parameters propagated.
B : Ext.orientation parameters regarded as error free.

Figure 7 : Predicted versus measured at image scale.

The predicted errors are pesimistic when using the actual error estimates for the exterior orientation elements. The reason might be that the 62 check points were obtained photogrammetrically, using the same orientation parameters as for the rectification. We expect that a remeasurement of the check points by an independent survey will give results in accordance with the predicted in column A of figure 7. In the meantime we are quite satisfied with the results.

4.3 TESTING THE MOSAICKING SUBSYSTEM

After visual inspection, the radiometric equalization of the patches was regarded satisfactory.

4.4 TESTING THE ANALYSIS SUBSYSTEM

Two points were tested. First, the possibility of detecting a mismatch between an obsolete DTM and the correct images was studied. For that purpose the DTM points along and in a neighborhood of a highway were changed to their approximate values before its construction. This test was rather subjective and our operator participated intensively in the discussion of the results.

The superimposition of the contours worked perfectly as expected from everyday practice. By the anaglyphic method, the orthophoto and its stereomate were observed stereoscopically at the image processing system display screen. The DTM irregularities were only detected partially and that was disappointing for both the authors and the operator. Nevertheless, we will still pursue this experiment under better conditions. The substraction of the orthopohotos generated with adjacent images was, as well, disappointing.

The most interesting and still pending experiment is the estimation of metric accuracy by correlation techniques.

5 ON THE COMPUTING TIME OF THE "BATCH" D.I.R. PROCESS

The first "big problem" of DOG is the long computing time of the rectification. In our first reported experiment (Arbiol et al. 1987) the consumed CPU time for the generation of an orthophoto of 2300 * 2300 pixels (1 pi : 50 mu at image scale) was 184 minutes in a VAX 11/750 with FPA unit. With that we were far away from any reasonable performance. After that, we reprogrammed the DIR "development" module to a "production oriented" version. This reprogramming changed the algorithms in the sense of working with image blocks instead of image columns. The reprogramming eliminated also most of the subroutine nesting used in the development version. A third version was developed, this time for a CSPi Mini-Map array processor attached to a VAX 11/780. Figure 8 gives the computing times for the three versions along with some reference figures.

	MFLOPS real*4	MIPS nominal	MWhets/sec real*4	CPU minutes	elapsed minutes
VAX 11/750 dev. version	0.11	0.6	0.75	184	204
VAX 11/780 prd. version	0.25	1.0	1.20	7.8	8.9
VAX 11/780 and CSPi	0.25 6.00	1.0 -	1.20 -	2.9	8.1

Figure 8 : Measured computing times for DIR.

For the generation of the same orthophoto with a smaller pixel size (1 pi : 22.7 mu at image scale) which is more in accordance with resolution standards, the given computed times can be extrapolated to 31.2 minutes for the VAX/11 780 production version and to 11.6 minutes when using the array processor. We admit that due to lack of expertise in programming the array processor, the results might be improved by a factor of 1.5 to 2.

Based on vendor Whetstones figures we can extrapolate the computing time for DIR (pi : 22.7 mu) to about 10 minutes CPU time for a SUN-3/200 with FPA unit which is our proposed workstation for DOG.

6 ON THE STORAGE REQUIREMENTS

The second "big problem" of DOG is the enormous storage requirements. We reproduce most of the table on figure 9 from Wiesel (1985), which is computed for aerial photographs of 23 cm * 23 cm.

PIXEL SIZE (in mu)	AMOUNT OF DATA (in MByte)
12.5 * 12.5	323
20 * 20	126
22.7 * 22.7 (GPM-IV scanner)	98
25 * 25	81
50 * 50	20
100 * 100	5
224.6 * 224.6 (work images)	1

Figure 9 : storage data for digital images.

For the following discussion we will consider the situation where a digital orthophoto of 2300 m * 2300 m has to be generated, input and output pixel size will be 22.7 mu. To fulfil the demands of the proposed concept the following data should be "at hand": work images for the preparation, orthopohotos pending of analysis, orthophotos in progress and mosaics in progres or pending. The total amount of storage for the data is listed in figure 10.

CONCEPT	N. OF ITEMS	STORAGE
Work images for interactive preparation	24	24 MB
Orthophoto analysis (pending or in progress)	6	126 MB
DIR in progress (input images)	2	42 MB
DIR in progress (output orthophoto)	1	21 MB
mosaic in progress (input)	1	21 MB
mosaic in progress (output)	1	21 MB
total amount of storage		255 MB

Figure 10 : storage for a combined batch-interactive session.

Therefore, typical minimal storage for a session is about 300 MB. The data for a typical orthophoto project, always reproducing an example from our Institute, will be as given in figure 11. Actually, the critical storage requirements come from the digitized images, since the orthophotos will be output on tape as soon as they are ready for the raster plotter.

CONCEPT	N. OF ITEMS	STORAGE
Work images for interactive preparation	100	100 MB
Input digital images	100	9800 MB
Digital orthophotos	96	2016 MB
DTMs	96	9 MB
total amount of storage		11925 MB

Figure 11 : total storage for an orthophoto project.

From the above considerations the storage needs are clearly defined: not less than 300 MB for a single interactive-batch session and about 10 GB for the digital imagery. The first group of data requires fast random acces capabilities whereas the second group requires large storage capability but not necessarily fast access.

As a conclusion, our system prototype will be based on a hierarchy of storage consisting on slow high capacity WORM optical disks (2.5 GB, 150 ms access time, 250 KB/s sustained transfer rate) and fast medium capacity standard disks (347 MB, 18 ms access time and 1.8 to 2.4 MB/s transfer rate). The interactive tasks will work on data stored in magnetic disk. Batch tasks can wait, if necessary, for the transfer from the optical disk. The only interactive task which needs random access to the optical disk is the correlation (if multiphoto correlation is used) for the evaluation of the metric accuracy. But, in this case, the amount of data is quite small.

7 HARDWARE CONFIGURATION OF THE DOG SYSTEM

From all the former considerations we conclude that:

- It is worth to start the development of the prototype without an array processor.
- The system should have interactive graphic and image processing capabilities.
- Although the subsystems for interactive raster editing have not been discussed in this paper, the DOG system must be able to deliver a finished raster product ready for plotting.
- It should be enough CPU time for the interactive editing while the batch processes are running.

The prototype will be build up around a SUN 3/260G workstation (4 MIPs, 0.87 MFLOPs, 3.43 MWhets/s) with 16 MBs of main memory, FPA unit, a 19 inches 1152 * 900 resolution monitor, and 2 * 347 MBs standard VME disks.

As a development prototype several questions are still open, among them:

- Use the WS as an image processing system. By using this approach we risk to get too high response time for image display operations. Since we have no experience with images in our SUN 3/110 we leave this point for further decision.
- Attach the optical disk drives and the tape unit to a remote file server in an Ethernet local area network. The penalty for that might be a slowdown in the accesses to the optical disk.

8 CONCLUSIONS

Our general conclusion is that it is possible to set up a completely digital system for the generation of orthophotos. In the next months and if the validation phase is concluded succesfully, our Institute will start the realization phase by producing a prototype.

We still have to develop or borrow from somebody else some software modules. That is true indeed for a photogrammetric least squares correlation subsystem, which we only have for elemental operations. Many investigations and tests are still to be performed, specially those concerning the real performance of the proposed hardware. But we note that with the proposed configuration we will benefit from the open characteristics of the hardware and software elements, and we hope we are not trapped by any unforeseen problem that could arise in a more closed system configuration.

To end with a photogrammetric remark, digital orthophoto generation can offer a more accurate and more controlled product.

9 REFERENCES

Alberich,Ll.,1985, Orthophotomapping with an automatic system at 1:5000 map scale. ASP-ACSM Convention, Washington, Vol. 1, pp. 222-228.

Albertz,J.,Koenig,G.,1984, A digital stereophotogrammetric system.

International Archives of Photogrammetry and Remote Sensing, Vol. XXV, Part 2a, Com. II, ISPRS Congress, Rio de Janeiro, pp. 1-7.

Arbiol,R.,Colomina,I.,Torres,J.,1987, Experiences with Gestalt DTM for digital orthophoto generation. ASPRS-ACSM Convention, Baltimore, Vol. 4, pp. 177-187.

Allam,M.M.,1978, DTM application in topographic mapping. ASP DTM Symposium, St.Louis, pp. 1-16.

Ebner,H.,Reinhardt,W.,1987, Verification of DTM data acquisition and digital contours by means of optical superimposition. ASPRS-ACSM Convention, Baltimore, Vol. 5, pp. 82-88.

Fernàndez,J.,1986, An overview to the Diniralt system. Internal report of the "Institut Cartogràfic de Catalunya", Barcelona.

Gaydos,L.,Ladner,L.,Champion,R.,Hooper,D.,1986, The production of orthophotographs by digital image processing techniques. ASPRS-ACSM Convention, Washington, Vol. 4, pp. 241-249.

Gruen,A.W.,1986, The digital photogrammetric station at the ETH Zurich. ISPRS Comission II Symposium "Photogrammetric and Remote Sensing Systems for data processing and analysis", Baltimore.

Gruen,A.W.,Baltsavias,E.P.,1987, High precision image matching for digital terrain model generation. International Archives of Photogrammetry, Vol. XXVI, Com. III, ISPRS Comission III Symposium "From analytical to digital", Rovaniemi.

Jaksic,Z.,1984, Photogrammetric Processes and Systems. International Archives of Photogrammetry and Remote Sensing, Vol. XXV, Part 2a, Com. II, ISPRS Congress, Rio de Janeiro, pp. 271-281.

Sarjakoski,T.,1981, Concept of a completely digital stereoplotter. The Photogrammetric Journal of Finland, Vol. 8, No. 2, pp. 95-100.

Wiesel,J.,1985, Digital image processing for orthophoto generation. Photogrammetria, Vol. 40, No. 2, pp. 69-76.

Wiesel,J.,Behr,F.,1987, Digital orthophoto generation using the KERN DSR-11 analytical stereo restitution instrument. ASPRS-ACSM Convention, Baltimore, Vol. 2, pp. 216-224.