DIGITAL PHOTOGRAMMETRIC SYSTEMS AT THE I.C.C.

I.Colomina, J.Navarro and M.Torre
Institut Cartogràfic de Catalunya
Balmes, 209-211
E-08006 Barcelona

Abstract

The photogrammetric and mapping digital systems developed at the *Institut Cartogràfic de Catalunya* (ICC) for the production of orthophotomaps are described. The rationale behind the paper can be summarized as follows: it is not the same to produce several orthophotos as it is to produce thousands of them nor is it the same to produce an orthophoto as it is to produce an orthophotomap. Factors for high production rates of orthophotos and orthophotomaps are, therefore, the addressed aspects.

1 Introduction

In 1982, short after the foundation of the ICC, the almost absolute lack of topographic maps at 1:5.000 scale and a limited coverage at 1:25.000 scale was the context in which the decision of setting a Gestalt Photomapper IV (GPM-IV) into production was made [1]. Very fast orthophoto and elevation data generation were the goals of the project in an attempt to provisionally fill the cartographic gap with orthophotomaps. The project had the additional benefit of triggering research and development activities in the field of digital photogrammetry [9] and terrain modelling [10].

Thus, in 1984 [9], the hardware and software of the GPM-IV were modified to allow for a digital output of the orthophoto and of the digitized aerial images. After that, the way for in-house development of a Digital Orthophoto System (DOS) was paved. In 1986, the photogrammetric and numerical aspects of orthophoto generation were investigated: metric accuracy, radiometric resolution and computability (anchor point approach). By 1987, a DOS concept was already available [2,3,6].

The first operational system was installed in 1988 [7]. It was able to produce up to 15 orthophotos per day on a Microvax 3600. At that time, the old but accurate GPM-IV was used as a flat bed digitizer. In 1990, the system was expanded with interactive mosaicking and completed with a digital mapping system for the assembly of the final orthophotomap product (raster orthophoto and vector map sheet data) which replaced the traditional photomechanical steps.

The above activities were complemented with the development of a raster countrywide elevation database and a bundle triangulation system. Apart from the

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invaluable expertise gained through these developments a remarkable level of integration between the DOS and the rest of related systems has been thereby achieved.

Although the paper concentrates on digital systems for conventional aerial imagery it must be mentioned that mapping from satellite images has been performed as well at the ICC since 1982. In particular, since 1987 small scale B/W and color orthophotomap series have been produced from SPOT imagery [4,5].

2 System concept

From the photogrammetric stand point, the orthophoto system of the ICC has been conceived on the bases of three main principles: the system has to be solely an application system of a general photogrammetric (digital) system; it has to be a fully automatic industrial system; and it has to be, when required, an interactive ortho-by-ortho system. From the map publishing stand point, the elimination of all manual photomechanical steps has been pursued.

The concept of a digital photogrammetric system (DPS) able to master any photogrammetric data capture function has been extensively described in the literature. From the very beginning, when the concept of the orthophoto system was laid, the idea of a *partial realization of a DPS* was already adopted [3]. Key aspects of the original concept are discussed in [8].

The requirement that the system be an industrial one has to do with throughput. Key points to high performance are full automated production workflow, optimized CPU-disk requirements and comprehensive project management capabilities [8].

Interactive operation modes are mainly thought for project design, quality control and actual orthophoto production in particular or troublesome cases. Demo-orthophotos or images with poor registered fiducial marks are examples thereof. As it is well known, the key point here is user interface ergonomy.

3 The Digital Orthophoto System (DOS)

The DOS of the ICC, code named ORTO, has been in operation since July 1988. Since then it has undergone a major improvement revision of its functionalities and user graphic interfaces. The third release, currently in production, was delivered in July 1990. The ORTO system has two relevant features: the project management utilities and the automation of the rectificator, from the selection of the optimal images to the orthophoto through automatic inner orientation.

3.1 The DIR subsystem

The DIR subsystem is the photogrammetric rectification nucleus. The main features of this subsystem -from the user's point of view- are listed below.

Mosaicking. This option is a must when the terrain is rather sloppy or the scale of the flight does not allow the production of the orthophoto from a single photograph.

Arbitrary rectification areas. The rectification area is defined in the object space through arbitrary closed polygons. For large map scales the polygon contains only the four corners which define the map frame. For very small map scales and special requests this is a useful option.

Stereomates. It is possible to produce a digital stereomate of the orthophoto in order to perform three dimensional quality control.

Controllability. The user may stop and restart the subsystem, notify the unavailability of a specific device as a tape unit, stop the execution of any orthophoto or get the information about the current state of the process, etc.

Some technical features of the DIR subsystem should also be stressed because of their relevance: DIR has been conceived as a *batch, pipelined, distributed, flexible and robust* system.

Batch. It is highly automated with a very low degree of human intervention. In fact, the operators only have to mount and dismount the tapes that the own DIR subsystem automatically requests.

Pipelined. The whole process is split into several steps which can be overlapped, so several orthophotos may be rectified at the same time and the productivity is highly increased. See section 3.2.

Distributed. The steps composing the rectification process may be executed in different CPUs. In this way the performance of each particular configuration is optimized.

Flexible. DIR was designed and implemented taking into account that the configuration might be modified at any moment, so no changes in the software are needed in such a case. The user, and the data processing department benefit from this feature.

Robust. DIR is able to restart without loss of information -and without human intervention- in the case of a computer breakdown.

3.1.1 Software design and implementation aspects

Although the software nuclei -rectification and general image processing, automatic inner orientation, reformatting, etc- have been designed following the criteria of maximum portability and standardization, other components of DIR, mainly the control software of the subsystem (see section 3.2), have been implemented using the capabilities of the VAX/VMS environment in order to increase the productivity. That means that ORTO, as many other software products, is not a fully portable system. Nevertheless, the migration to other environments could be done with a reasonable effort.

All the in-house developed software has been written with the standard subset of the VAX/VMS version of the FORTRAN-77 programming language. The interactive windowing environment chosen was DECWindows and the standard X-Windows graphic library.

3.2 Pipelining and routing in the DIR subsystem

The DIR subsystem has been implemented using a pipelined conception. The processing of the orthophoto has been split into several steps or phases.

A control or master process (DIR control process) is in charge of the management of the coordination of such steps. This master is aware of all the details related to the configuration (number of disks, tapes, the state of these, etc), to the needs of each step in terms of resources as well as to the whole state of the process. Whenever it is possible –that is, when enough resources are available– a new step is started by the master. Once a step has been completed, the master is notified so the state of the system is changed. The orthophotos are processed according to a *first-in-first-out* criterion. If an orthophoto can not be processed because of the lack of resources, it is possible however to start a later one provided that it is not affected by this problem.

At any moment, all steps of the pipeline can be busy working with next orthophotos in the job-scheduling list. Moreover, these steps may be authorized to process more than one orthophoto simultaneously; this is a useful feature, because it allows the balancing of the differences existing between the processing times of the phases, thus lowering the waiting times due to the lack of data and increasing the productivity. A layout of the DIR subsystem is shown in Figure 1.

The set of phases required to generate an orthophoto depends on the processing parameters selected by the user (preprocessing subsystem). A *circuit* is the set of steps used to process an orthophoto according to a specific group of processing parameters. If any of these are changed, then a different circuit has to be used.

The main advantage of this concept lies in the fact that the pipelined implementation of DIR allows the determination of the sequence of tasks to be performed and to connect them in any way they are wanted. If a new feature is requested by the user –for instance, a new algorithm to improve the radiometry of the image– then only the specific software has to be written. The new feature is defined as a new step of the DIR subsystem and a circuit is added to the existing ones.

The steps and circuits may be added to and deleted from the DIR subsystem without changing the software. Only the DIR configuration files must be modified. An orthophoto must be processed according to one of the predefined circuits. The concept of the circuit is depicted by figure 2.

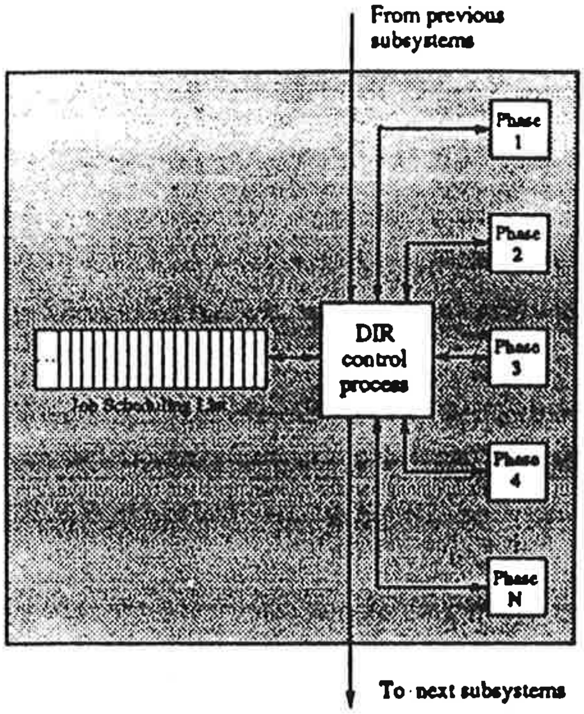

Figure 1: DIR subsystem.

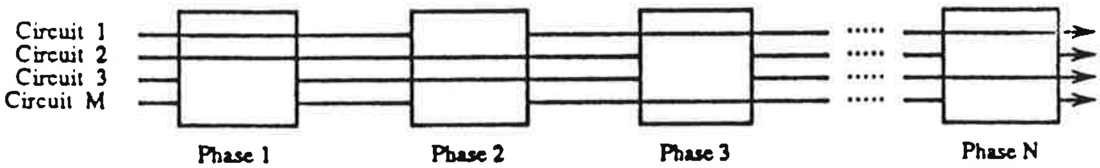

Figure 2: DIR subsystem's circuits.

4 Orthophotomap generation system

Since September 1990, the tasks related to the finishing of the orthophotomap have been passed over to a digital environment using Intergraph hardware and software. The overall system conception as well as many software modules have been developed at the ICC. Benefits of this conception are: preservation of the quality of the digital orthophoto and suppression of all photomechanical laboratory tasks for integrating the different components of the orthophotomap on a single film.

Several elements are required to build the orthophotomap (Figure 3), which may be classified as raster and vector components. Up to four vector components are merged with the orthophoto which is the only raster input.

Figure 3: Digitally assembled orthophotomap of the 1:5.000 series.

Isometric terrain view (upper left corner). Software modules had to be developed for the generation of perspective views. Main features of these modules are: direct access to the DTM database, hidden-line removal techniques and interactive selection of the *best viewing point*.

Index map (upper right corner). To locate the orthophotomap in a smaller map scale context (1:50.000), an index map is drawn. Tailored administrative and topographical databases are used.

Map frames and legends. A file containing additional vector information –geographical and map projection coordinates, geodetic & photogrammetric data, legends, ICC's logo and anagram, etc.– is automatically generated through access to the corresponding databases.

Toponymy. Using the orthophoto as background, the geographical names are interactively placed on the screen by an experienced operator on a fully *WYSIWYG* environment. Since the text uses BitStream shapes (vectors) the names can be easily moved, rotated or placed along the geographic relevant features of the terrain according to the type and font specifications stored in a file. Once the position of the geographical name has been validated, its coordinates are fed back to the database. Thus, the name placement process updates a georeferenced toponym database useful for GIS applications.

In order to achieve the final distribution of all the elements integrating the orthophotomap the isometric view and the index map are automatically scaled, rotated and moved when necessary.

Once the previous inputs have been generated, a raster file combining all of them is created by the *mappublisher* process, which is composed of three steps. First, the vector information is rasterized and two different files are created containing black vector data –using BitStream high resolution fonts for the texts– and white text outlines (masks) for the geographic names. Afterwards, these files are merged with the orthophoto in order to obtain the orthophotomap which is, finally, electronically halftoned and plotted with 133 dpi screens at 1016 lpi resolution on the Optronics 5040.

Since the merging was done in the raster domain at 25 μm resolution, a great amount of disk space was required by the process (about 350 MB per orthophotomap). A new version of the Intergraph MapPublisher software allows the merging with a much lower disk usage (about 40 MB). To achieve that, the merging is done directly *on-the-fly* by the raster-plotter driver. Expected throughput increase is about 30%. Testing of this software is under way at the ICC.

5 System hardware: configuration and performance

Figure 4 depicts the hardware configuration, which was designed taking into account the available resources and the existing and future applications.

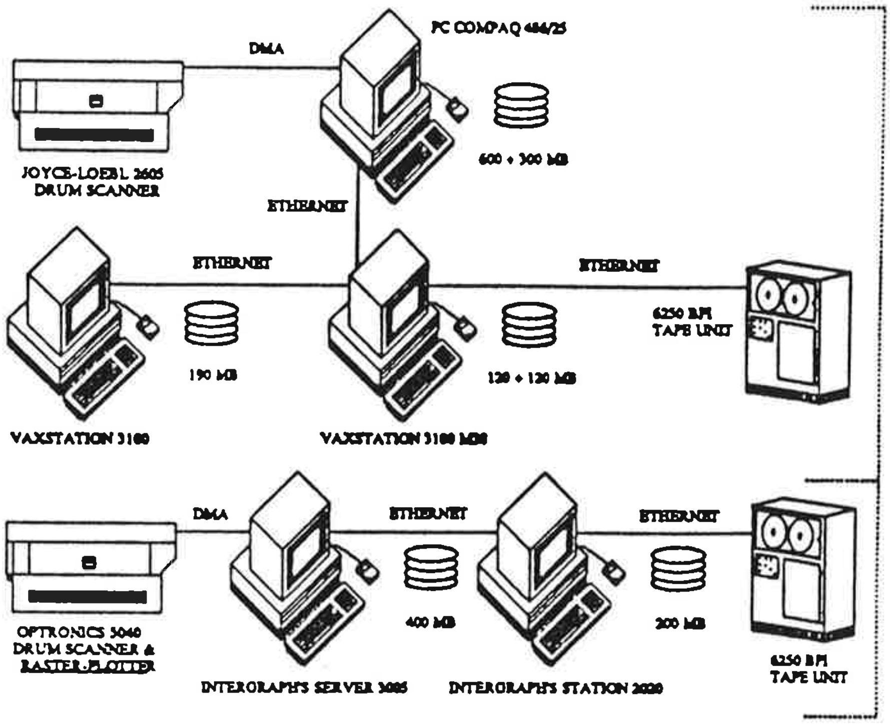

Figure 4: Hardware configuration.

Two main groups may be identified within this configuration. The first one is in charge of generating the orthophotos whereas the second one is dedicated to the production of halftone films using the raster-plotter.

Orthophoto generation

Joyce-Loebl 2605 drum scanner. Pixel sizes: 12.5, 25, 50, 100, 200, 500 and 1000 μm. Drum speeds: 1, 2, 5 and 10 rev/s. Maximum image size: 1000 mm × 1200 mm. B/W and RGB. Scanning modes: reflectance and transmission. Density ranges: 0-2.0D and 0-4.0D.

PC Compaq 486/25 with 4 MB of RAM and 600 + 300 MB of disk space. It controls the scanner, which is connected by DMA interface.

DEC Vaxstation 3100 M38 with 8 MB of RAM, 120 + 120 MB disk, 2300 double precision Whetstones (DPW). Almost all the tasks related to the DOS are executed by this computer. Digitized images are transferred from the scanning subsystem over a 10 Mbits/s Ethernet.

When mosaicking is required, a second workstation is used. This was decided in order to avoid raising the workload of the first workstation, which is fully dedicated to batch production. The tasks to be performed by the second CPU are thus the rectification and assemblage of the mosaic components. The time required to

STEP	Read input tape	Tiling	Inner orientation. DTM capture	Rectification	Windowing (Map Framing)	Write output tape
CPU (min)	1	4	1.5	35	1	1
Disk (MB)	40	40	≈ 0	25	25	0

Table 1: Costs for one orthophoto (Vaxstation 3100 M38).

perform the interactive assemblage of the mosaic for 1:25.000 and 1:5.000 map scale sheets is about 45 and 60 minutes respectively. In a former configuration, all the processes were executed on a single workstation. The migration of the mosaicking tasks to the second unit was done with no modification of the software, which was designed taking all these principles into account. The second workstation is currently a *DEC Vaxstation 3100*, with 8 MB of RAM, 190 MB of disk space and 1600 DPW.

6250 bpi tape unit. Used to read/write the tapes containing input digital images/orthophotos.

Orthophotomap assembly and output quality plotting

Intergraph Workstation 2020, with 16 MB of RAM, 200 MB disk, about 5000 DPW and 12.5 MIPS. It is used to place the toponymy and generate the vectorial information.

Intergraph Server 3005, with 16 MB of RAM, 3×670 MB disk, 4100 DPW and 10 MIPS. It is used to read the tapes generated by the DOS and send them to the raster plotter once they have been processed by the Workstation 2020.

Integraph Optronics 5040 drum scanner and raster plotter. Pixel sizes: 12.5, 25, 50, 100 and 200 μm (round & square). Drum speeds: 500 and 1000 rev/s. Maximum image size: 1270 mm × 1016 mm.

The costs of generating an orthophoto are shown in Table 1. They are referred to the 1:5.000 map scale series, which is the main orthophoto product of the ICC. The whole process has been split into the six steps which it is composed of.

It is easy to check that the total CPU time required to generate a single orthophoto –including *all* required steps, not only the digital image rectification– is about 42 minutes. On the other hand, it is *not* necessary to have 130 MB of disk space. In fact, a much smaller amount of space, 80 MB, is enough to perform the

MODE	Read tape	Create frames	Toponymy placement per oper.	Map-publishing	Raster plotting	Average per map
Pipelined	30	≈ 0	120	60	60	120
Expected on-the-fly	30	≈ 0	120	90		90
Ortho-by-ortho	20	≈ 0	120	35	45	220

Note: the orthophotomap (82 cm × 75 cm) is plotted at 25 μm; units are minutes (ellapsed).

Table 2: Costs and performance of the orthophotomap system.

process. The reason is that as soon as a step has been completed, the files created by the previous one are deleted.

With one Vaxstation 3100 M38 CPU, ORTO is able to produce up to 21 orthophotos per day if both input and output images are read from or written onto a tape (as shown in Table 1). If the input image is read from a disk, then the performance is increased up to 30 orthophotos per day.

The orthophotomap generation system is also pipelined. The costs of generating an orthophotomap as well as the performance are shown in table 2. To illustrate the benefits due to the pipelined organization, results for a hypothetical ortho-by-ortho workflow are also given.

5.1 Tuning of the hardware configuration

In order to improve the performance of the DIR subsystem, some tests have been performed concerning the tuning of the hardware configuration. Because of the complexity of the subsystem and the unavailability of some resources, simulation techniques have been used.

Even though the processing time is a key factor, it is not the only one affecting the final throughput. Other components of the system, such as the amount of disk space and the number of tape units, have to be taken into account to obtain a significant increase of the productivity. Otherwise, the bottlenecks produced by unbalanced configurations would lower the production rates.

Results of some possible configurations are presented in table 3. It is of special interest to note that the actual throughput may be increased by a factor of two (from 21 to 42 orthophotos per day).

Disk usage (Mb)	Tape units	Processing time	Orthophotos
120 + 120	1	100 % ◁	21
600 + 600	1	100 % ◁	30
120 + 120 ◁	1	70 %	34
160 + 160	1 ◁	70 %	38
160*+ 160 ◁	2	60 %	42

Note: ◁ stands for bottleneck.

Table 3: Performance of simulated configurations.

6 Conclusions and prospects

The orthophotomapping system of the ICC is, with the exception of the DTM generation, a full digital high performance operational photogrammetric and mapping system. In its current status the photogrammetric component of the system is able to produce up to 30 orthophotos per day and the mapping component of up to 0.5 orthophotomaps per hour. It is pointed out that high performance means high flexibility under real operational conditions since the system can absorb workload peaks.

Undergoing development steps are the integration of the new Zeiss-Intergraph PS-1 digitizer into the system and the color option including mosaicking. After that, the interactive operational modes (ortho-by-ortho and quality-control) will be realized, thus concluding the bulk of the system development and opening a new development period. Prospects for research and development activities in the field of digital photogrammetry are related to the assisted interactive derivation of heights for production and quality control tasks.

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