ON FUNCTIONAL REQUIREMENTS OF A PHOTOGRAMMETRIC STATION FOR DIGITAL ORTHOPHOTO GENERATION*

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

Abstract.

In this paper the realizations of digital photogrammetric systems at the ICC are presented. Functional specifications and recommendations for the design and evaluation of systems for digital orthophoto generation are given. These requirements are drawn after more than three years of practical experience in the development and operation of the system in a production environment. Finally the paper describes relevant design and implementation aspects of the current system configuration which is able to produce up to 30 orthophotos per day on a 3.8 Vups DEC Vaxstation.

1 Introduction.

Since 1986 digital photogrammetric systems have been developed at the *Institut Cartogràfic de Catalunya* (ICC) which have involved some of its teams: the development group of geodesy and photogrammetry, the group of remote sensing and image processing as well as some members of the production department [1,2,5,6,8]. In a last step, the overall system performance was significantly optimized by the computer systems department.

One of the results of the work of this heterogeneous group is that since 1988 the ICC has been producing orthophotos in digital output formats, by digital means, on general purpose hardware platforms and with in-house written software.

Besides the pure cartographic strategic decision to produce a broad range of orthophotomap series, development activities in digital photogrammetry started when it was considered that conditions to open a development line in the area of digital photogrammetry were met at the ICC. First, the expertise was there in the main fields involved: classical photogrammetry, image processing, system's integration and design. Secondly, it was about the time to start the building up of a workstation with photogrammetric data capture capabilities (i.e. a digital photogrammetric station) beginning with the easiest part: orthophoto production.

In-house research and development of components of a photogrammetric digital system which can be further independently assembled or integrated with third party systems is motivated by the ICC institutional responsibilities and practical needs. In 1987 when the coding of the first Digital Orthophoto System (DOS) operational version started there was no commercial system available which could met the ICC automation and production rate requirements. In 1991 at least one airborne new digital sensor will be tested by the ICC. Therefore, for our advisory, educational, research and testing activities it is a must to have open access to photogrammetric software.

2 Orthophoto generation in the frame of a photogrammetric system.

In addition to a number of software nuclei whose existence and characteristics are dictated by the current status of imaging sensors technology –for instance, the orientation modules for aerial metric camera or SPOT HVR images– there are, essentially, few basic application subsystems which correspond to the basic modes of photogrammetric acquisition or revision of spatial information. These modes are the result of combining the answers to two questions: whether there is a need for a geometric object reconstruction (GR) and whether there is a need for image interpretation (II); and can be summarized as follows

- orthophoto generation (no GR, no II),

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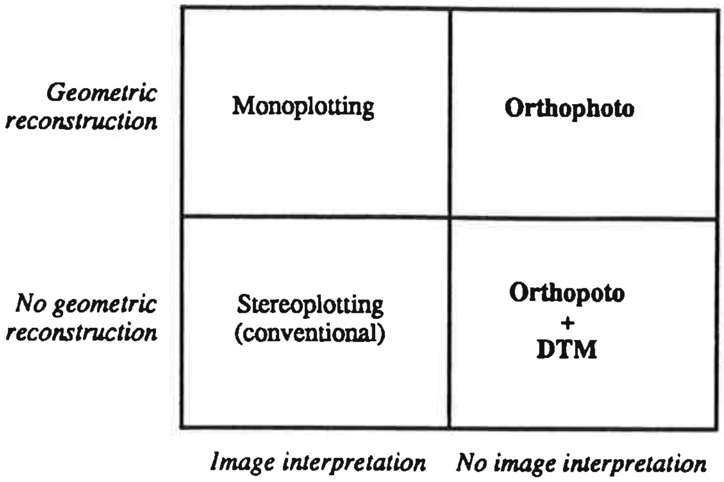


Figure 1: Basic modes of photogrammetric data capture.

- monoplotting (no GR, II),
- DTM generation (GR, no II),
- stereoplotting (GR, II).

The concept of a digital photogrammetric system is today well established and will not be repeated here [7,9]. At the ICC, since the very beginning, the development of the digital orthophoto system has been regarded as the development of an application subsystem of a general photogrammetric system. Other components of the system are either being developed (automatic derivation of elevation data) or being integrated (3d stereoscopic display) or being purchased (PS-1 Intergraph-Zeiss high precision scanner).

3 Requirements for orthophoto generation.

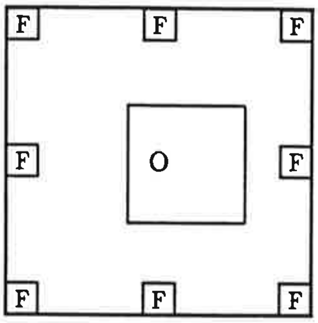
Given the elevation data, a digitized image, inner and outer orientation elements and calibration parameters, the generation of a digital orthophoto is a very easy task indeed. There are no real-time requirements neither in the rectification loop nor in the resampling, storage and transfer of data for image roaming. However, because of this lack of critical specifications it is natural to expect from a DOS system a high degree of automation as well as a balanced low cost hardware/software configuration. In other words the potential user is likely to put his demands in the capability of a high production rate with as limited as possible human intervention without resorting to too expensive a configuration. It is accepted that, depending on other factors, hardware/software upgrades of a basic configuration might be of interest.

The above considerations are the starting point for an additional list of functional requirements which the authors have collected during three years of experience under real operational conditions. The general design and functional requirements were already given in [2].

Although it may be regarded as a peripheral device of the photogrammetric station some remarks will be devoted to scanners for 230 × 230 mm ^{2} aerial images since they will still provide the bulk of imaging data for many years.

Scanners. A/D convertors for aerial images.

1. Geometric accuracy. Should be better than 10 μm. Otherwise the map-image scale ratio might have to be reconsidered.
2. Radiometric resolution. 10 to 12 bits per pixel assures the full radiometric range of the photograph to be captured without any loss and allows further radiometric enhancement by image processing techniques.
3. Standardization. A choice of standard formats should be available as well as the possibility of integrating conversion modules to other formats.



F: correlation area for fiducial marks

O: effective area for rectification

Figure 2: Selective digitization.

4. User definable procedures. Most of times only a region of the image is to be rectified (figure 2). This area can be computed a priori. The rest can be either not digitized or not transferred to the photogrammetric station with a saving of up to 65% of digitising or transfer time. Selective digitization is an instance of a user definable procedure.

Some of the items above must and can be easily tested before the purchase of a scanner. A grid on a film measured with a monocomparator can be used to check the geometric accuracy and stability of the scanner. Unfortunately, most of commercially available scanners are less accurate than 10 μm. Radiometric resolution may have an influence not only on the orthophoto quality but also in the generation of the orthophoto itself. Consider, as an example, the situation where a poorly imaged fiducial mark has to be aimed at by image matching techniques. A radiometric troublesome aerial photograph can be used to asses the behavior of the scanner under unfavorable conditions.

Input/Output. Communication with other Data Processing Systems.

1. As the required input data is usually stored in different data processing systems a flexible interfacing facility is required. This has to do with particular user requirements as well as with national cartographic standards.
2. Output formats. The system should allow for different standard output formats and for the integration of conversion modules to other formats.

Orthophoto generation. Basic operation modes and performance factors.

1. Batch mode. This operation mode is likely to undertake the bulk of the processing task. A completely automatic workflow is a must. Selection of the optimal set of photographs, use of aerial or spatial triangulation derived orientation data, inner orientation, etc. have to be performed without operator's intervention.
2. Interactive mode. An interactive operation mode gives flexibility for testing, for filling project gaps. The functionalities mentioned in the former point should have an image-by-image interactive counterpart.
3. Mosaicking. Mosaicking is usually avoided because it slows down the production rates. As this is not always possible, a powerful and ergonomic graphic interface to define seams and a highly automated radiometric equalization between contributing orthophotos are, again, a must.
4. Color. The system should also be prepared to deal with color images. Mosaicking color images is not as straightforward as it might seem and some evaluation tests are advisable.

It is also important that the potential user be aware of some general design aspects which may strongly influence the overall system performance and the hardware requirements.

1. Workflow design. It can be shown [6] that naive system workflow organizations can slow down the throughput up to a factor of 2.

2. Internal image formats. Even taking into account the low cost of RAM memories some projects may exceed the computer capacity. In general a smart organization of image files (for instance patch-by-patch instead of row-by-row) allows for faster interactive operations and requires much less computer memory.

If the well established procedures and scale ratios are used, geometric accuracy will constitute no problem at all. After a few completed projects users become more and more confident of the geometric robustness of the system even with relatively inaccurate elevation data. The rather concentrate on checking the radiometric general quality and the absence of very big local image deformations due to unfavorable terrain slopes and occlusions. They also carefully check that the proper image was used.

Quality control.

1. Coarse inspection. Resampled images should be kept on disk so a coarse comfortable inspection by displaying of each orthophoto is possible.
2. Final inspection. A medium quality hardcopy (i.e. an electrostatic plotter) is normally used for a detailed inspection of the orthophoto once the coarse inspection has been gone through. The inspection of the softcopy with the obvious implications on data storage may be considered. In any case the decision is up to the user and the system should be prepared for that.
3. Metric accuracy. Automatic image matching techniques can be used but the user tends to carefully check each horizontal check-point. A semiautomatic or even manual measuring procedure will suffice.

The next set of specifications is surprisingly not found in many papers on digital orthophoto systems. Project management facilities are of paramount importance in medium an large production environments.

Project Management. DOS Control / Exploitation Subsystem / Production Workflow Monitoring.

A data base management system (DBMS) is the best tool for the implementation of these functionalities.

1. Project definition. The project invariant parameters (B/W or RGB, output pixel size, DTM interpolation parameters, etc.)
2. Managing levels. Access to system tuning parameters must be selective. Key project settings, for instance, may only be edited by the project manager.
3. Accounting and reporting facilities.

Although the authors are rather involved in software development than in actual production tasks, the above set of functionalities has been elaborated with the user stand point in mind. The reader will observe that some of the so far described requirements have not been yet implemented in the ICC system.

4 Designing a DOS: general aspects.

As mentioned, a digital elevation model, a digitized image and a set of orientation parameters are required to produce an orthophoto. From the strict photogrammetric point of view this information is enough to generate the rectified image. In addition, some complementary but essential data has to be provided to run a DOS. The definition of the map frame, the data acquisition subsystem, the organization of the quality control or the integration of the final image into other systems are examples of such data.

All this information may be arranged in several systems (see figure 3) which for the purposes of this article can be referred to

- Digital Terrain Modelling (*DTM*),
- Map Framing and
- Orientation.

These systems are independent of the process of generating digital orthophotos and may exist in order to fulfil other purposes.

A DOS itself is composed of several subsystems:

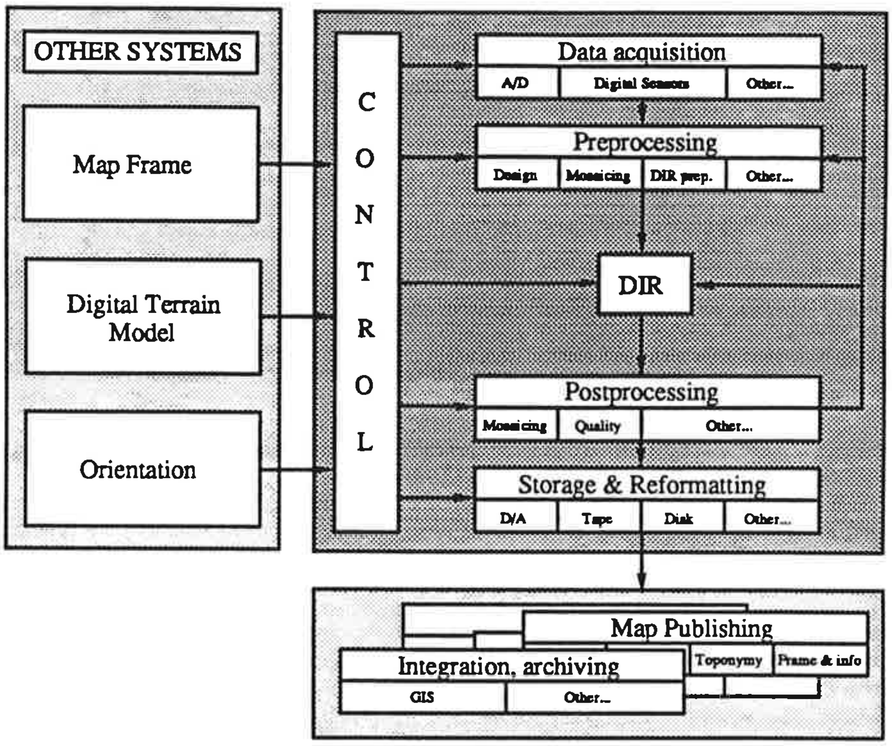


Figure 3: DOS: general scheme.

- Data (image) acquisition,
- Preprocessing,
- Digital image rectification (*DIR*),
- Postprocessing,
- Storage & Reformatting and
- Control.

The functions assumed by the previous subsystems are:

Data acquisition.
This subsystem is responsible for obtaining the input image to be rectified. There exist different sources where this image can be obtained from: digital sensors, scanned aerial photographs, etc.

Preprocessing.
Previously to the rectification of the digital image several operations have to be performed: definition of the parameters controlling the process (typically pixel size, desired output format, etc.), definition of the seam when the orthophoto has to be produced by means of mosaicking techniques, etc.

Digital Image Rectification.
The digital rectification of the input image is performed by this subsystem (figure 5).

Postprocessing.
Some processes have to be applied to the rectified image to obtain the orthophoto: enhancement (to improve the radiometric quality of the original image), mosaicking (in very occluded zones), quality control, windowing (to adjust the image to the map frame), etc.

Storage & Reformatting.

Once the orthophoto has been produced, it has to be stored and sometimes reformatted to be integrated into other systems.

Last but not least it is very important to stress the role played by the *Control* subsystem. It is responsible for the coordination of the different components of the DOS. Some of its functions are:

- To keep track of the whole state of the process. It is not the same to produce one orthophoto as one thousand.
- To provide a comprehensive interface between the user and the DOS.
- To guarantee the validity and correctness of the data being used and the proper execution of the different steps involved in the generation of the orthophotos.
- To guarantee the required feedback whenever an error is detected in order to detect and solve the problem and reprocess the orthophoto.
- To provide a mechanism for recovering the system in the case of a computer's collapse (shutdowns, power failures, etc.).

Figure 3 shows the relation between the subsystems integrating the DOS and also between the DOS itself and the other independent information systems (Digital Terrain Modelling, Map Framing, Orientation and other data bases).

The scheme depicted by figure 3 is an ideal one. Some systems must exist in any case (as the DTM, the Map Framing and Orientation) although different levels of complexity are possible. Others may offer only a subset of the functions listed above; for instance, if the orthophoto is always inside a single image and the terrain is flat enough, all the operations related with the mosaicking process (Pre- and Postprocessing subsystems) might be suppressed. Furthermore, the options offered by the Data Acquisition and the Storage & Reformatting subsystems may be reduced up to a minimum (for instance, scanning of aerial photographs on input and the generation of tapes on output).

The immediate consequence of this freedom is that it is possible to configurate a DOS in many different ways. It is the task of each organization to choose the one that will satisfy its needs. The implementation of the DOS of the ICC will be discussed in section 5.

5 The DOS of the Institut Cartogràfic de Catalunya.

The DOS of the ICC, *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.

5.1 General description.

ORTO is organized as shown in the scheme depicted by figure 3 although not all the functions of the different subsystems have been implemented.

- The three independent systems that provide the fundamental information to the DOS have been developed at the ICC and have been fully operational since long before the first release of ORTO was delivered. A great effort was spent in order to guarantee a high degree of accessibility, standardization and automatization, so the integration with ORTO was implemented with a very low cost.

  The Digital Terrain Modelling system was set up by means of a data base allowing on line queries. It was loaded with data provided by several photogrammetric devices: analog and analytical stereoplotters and the Gestalt Photomapper IV correlator (GPM-IV).

  The Map Frame subsystem may also be accessed on line. User defined map frames are supported.
- Up to the moment, the Data Acquisition subsystem allows only scanned photographs as input to the DOS. The selection of the photographs as well as the particular area within those to be scanned to produce an orthophoto is performed by a powerful DECWindows graphic application (*SELFOT* or *SELecció de FOTogrames*, selection of photographs). Two operation modes are available: fully automatic and user-controlled, the last one being used when mosaicking is required.

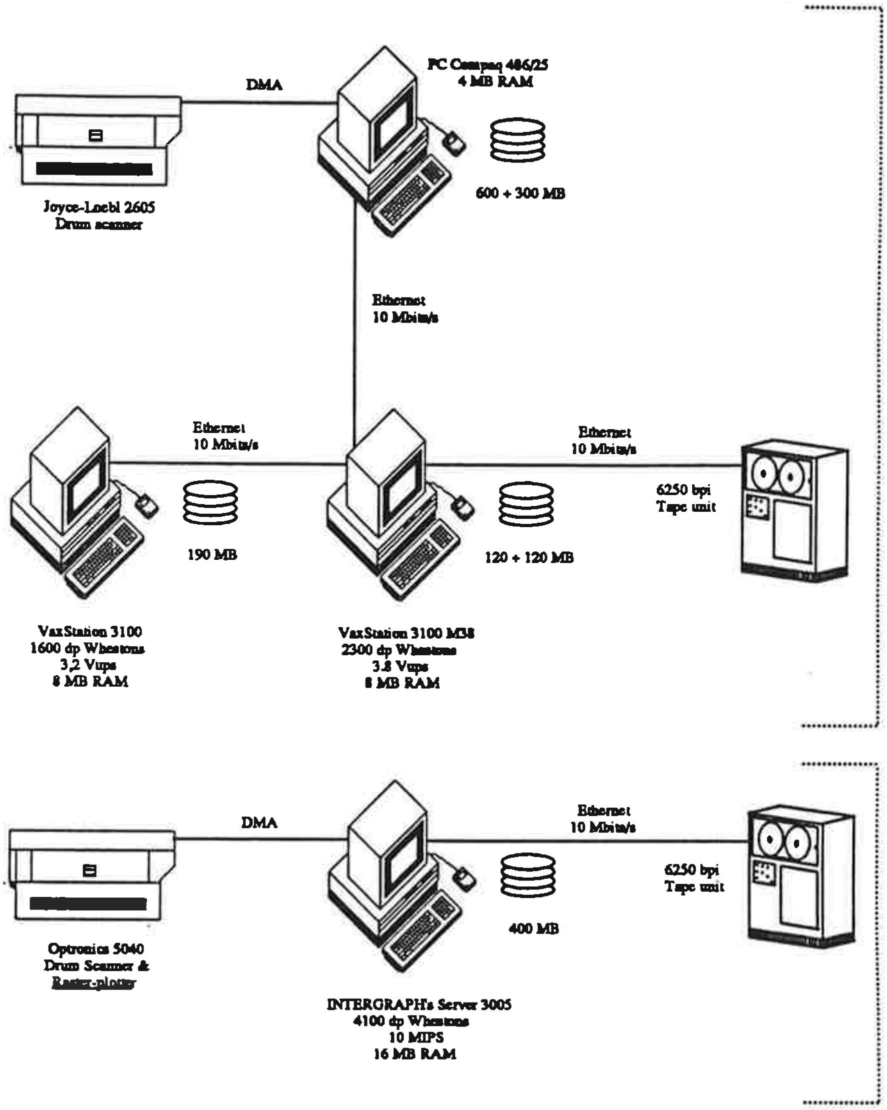


Figure 4: DOS of the ICC: configuration.

- Many functions are supported nowadays by the Preprocessing subsystem. Some of them are related to the management of the control parameters of the DIR subsystem but some others allow the user to specify, for instance, the kind of output device to be used on output, etc.
- The quality control and some tasks related to the mosaicking process (radiometric control etc.) are the main functions of the Postprocessing subsystem of the DOS of the ICC.
- Two storage options are offered by the Storage & Reformatting subsystem: disk and tape. Up to four different output formats are supported (depending on the raster plotter to be used to print the orthophoto): *Scitex, Handshake, Dr.Hell and the ICC's format.* If any further postprocessing is needed –as for instance the digital edition of the toponymy– then the ICC's own format is used.

The DIR subsystem is described in detail in section 5.3.

5.2 Configuration.

As discussed in section 4 there are many possible configurations to set up a DOS. Figure 4 depicts the one used by the ICC, which was designed taking into account the available resources and the existing and future applications running on it.

Two main groups may be identified within this configuration. The first one is used to generate the digital orthophotos while the other is dedicated to the production of hardcopies using a raster plotter.

All the in-house developed software has been written using only 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.

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 × 1200 mm ^{2}. B/W and RGB. Scanning modes: reflectance and transmission. Density ranges: 0-2.0D, 0-4.0D.
- PC Compaq 486/25 with 4 MB of RAM and 600 + 300 MB of disk space (two units). It is used to control the scanner connected by DMA interface.
- DEC Vaxstation 3100 M38 with 8 MB of RAM, 120 + 120 MB disk, 2300 double precision Whestons (DPW), 3.8 Vups[1]. 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.

  In a previous 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. In a next section these flexibility features of the software will be discussed.

  The second workstation is currently a DEC Vaxstation 3100, with 8 MB of RAM, 190 MB of disk space, 1600 DPW and 3.2 Vups.
- 6250 bpi tape unit. Used to read/write the tapes containing input digital images/orthophotos.

Output quality plotting.

- Intergraph Server 3005, with 16 MB of RAM, 400 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.
- 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 × 1016 mm ^{2}.

5.3 The DIR subsystem.

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

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 5.3.1), 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. Anyway, the migration to other environments could be done with a reasonable effort.

1. It is a *batch* system, 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.
2. It is a *pipelined* system. 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 5.3.1.

[1] The Vaxstation is *not* a RISC computer. One used performance parameter is the Vups –Vax units per second. Vaxstations cannot be compared to RISC machines by simply using MIPS. However, in order to allow for that comparison some benchmarks were run at the ICC performing image processing typical operations. According to those tests the equivalence 1 Vups ≈ 4 MIPS can be used.

3. It is a *distributed* system. The steps composing the rectification process may be executed in different CPUs. In this way the performance of each particular configuration is optimized.

4. It is a *flexible* system. DIR was designed and implemented taking into account that the configuration might be modified in any moment, so no changes in the software are needed in such case. Sometimes "flexible" means flexible for the developer, not for the user.

5. It is a *robust* system. DIR is able to restart without loss of information –and without human intervention– in the case of a computer's breakdown.

From the user's point of view the main features of this subsystem are:

1. It is independent of the orthophoto scale.

2. There is no limitation with respect to the flight direction.

3. There exists the possibility of processing orthophotos by means of mosaicking techniques. When the terrain is specially sloppy or the scale of the flight does not allow to produce the orthophoto from a single photograph, this feature becomes specially useful.

4. 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.

5. It is flexible. The user, for instance, may change some working parameters easily: number of fiducials to be used when performing the inner orientation, the inner orientation algorithm itself, input and output devices (disk, tape, etc.), output formats, etc.

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

7. It is tailorable. A virtually unlimited number of projects may be defined by the user so the orthophotos of different scales, pixel sizes, zones etc. may be efficiently managed.

8. It is easy to use.

Of course these are *obvious* features that any DOS should support. Anyway, it is not straightforward to design and implement a orthophoto production system having *all* these capabilities efficiently integrated. For example, the definition of the seam for a orthophoto produced using mosaicking must be done using a sophisticated graphic interface with zooming capabilities as well as a very good response time. Otherwise the process would be too difficult and time consuming, lowering the performance.

5.3.1 Pipelining and routing.

The digital image rectification subsystem has been implemented using a pipelined conception. The processing of the orthophoto has been split into several steps or phases. A very specific function is performed by each step.

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, 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. Anyway, if an orthophoto may not be processed because of the lack of resources, it is possible to start a later one providing 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 to balance the differences existing between the processing times of the phases, lowering the waiting times due to the lack of data and increasing the productivity.

The DIR subsystem and its pipelined organization is shown in figure 5.

The set of phases required to generate an orthophoto depends on the processing parameters selected by the user (Preprocessing subsystem). A *circuit* is defined as the set of steps used to process an orthophoto

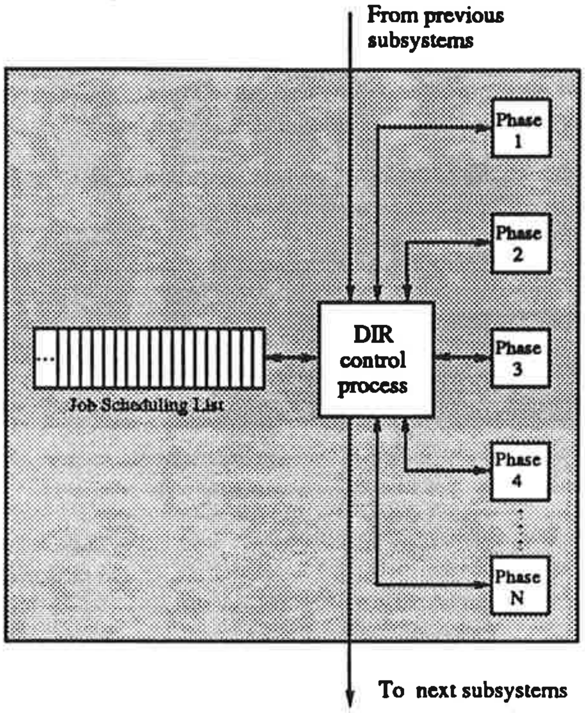


Figure 5: DOS of the ICC: DIR subsystem.

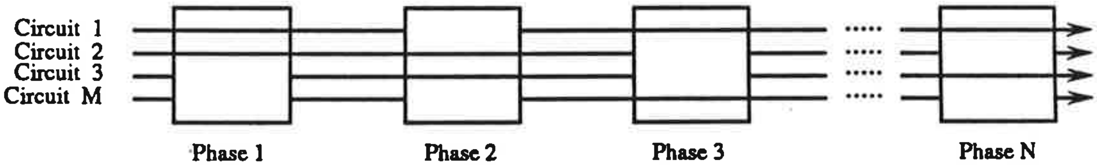


Figure 6: DOS of the ICC: DIR subsystem's circuits.

according to a specific group of processing parameters. If any of these is 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 to define very concrete tasks to be performed and to connect them in any way. 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's *configuration files* have to be modified.

An orthophoto must be processed according to one of the predefined circuits.

In fact, the DIR subsystem is nothing else than a *dispatcher*. Its task is to launch the execution of some tasks which are meaningless to it. How these tasks have to be connected is not a matter of its interest. It is the responsibility of the user to define these links using the circuits.

The concept of the circuit is depicted by figure 6.

5.4 Costs and performance.

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 orthophotogrammetric product of the ICC. The whole process has been split into the six steps which it is composed of.

STEP	Read input tape	Reformatting	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: DOS of the ICC: costs of producing one orthophoto on a Vaxstation 3100 M38.

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 side, it is *not* necessary to have 130 MB of disk space. In fact, a much smaller amount of space, 80 MB, will be enough to perform the 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 disk, then the performance is increased up to 30 orthophotos per day.

6 Conclusions.

It has been proven, not in the paper but in practice, that a high performance digital orthophoto system can be set up on a low cost general purpose hardware platform. Once a fully digital photogrammetric system has been put successfully into production, the way for more complex digital based procedures seams to be paved. This is a last but not less important benefit of the orthophoto system.

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