PRI²SM — Softcopy Production of Orthophotos and DEM

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ABSTRACT: The PRI²SM series of workstations are softcopy digital photogrammetric systems (Air-Photo PRI²SM, Air-Photo-DEM PRI²SM, SPOT PRI²SM, SPOT-DEM PRI²SM) designed to produce digital ortho-images from both aerial photographs and SPOT images. In areas of suitable terrain the "DEM" versions produces a DEM using the method of cross-correlation. The man-machine interface comprises an extensive set of menus, in the SUNVIEW environment. The considerable amount of data required for the generation of ortho-images is controlled using an INGRES database. The PRI²SM array processor runs at 25 mflops and for this reason large input images can be processed fairly quickly. The automatic DEM generation and editing component is a large part of the system, particularly for SPOT processing, where, due to the uniformity of the image, the cross-correlation method is particularly effective. A number of editing functions are available for the DEM. Extensive use is made of I²S System 600 image-processing software, and traditional image-processing tasks such as mosaicking and edge enhancement are available to the user.

INTRODUCTION

"SOFTCOPY" - SIGNALS THE START OF A TRANSFORMATION from the optical-mechanical technology that dominates photogrammetry today, to the world of raster imagery and the display of the aerial photograph on a computer monitor. The word softcopy is not very descriptive and perhaps the word "digital" would be better suited. "Digital photogrammetric mapping," however, implies digital capture of the vector data from a stereoplotter and has nothing to do with raster imagery. Without worrying too much about semantics, the trend to the raster domain is undeniable and one can already predict enormous advantages from this technology.

It is interesting to see that the first real practical application of this technology in the photogrammetric world was in orthophoto production systems and not in stereoplotters. Likewise, the first real practical application of digital recording of point data from a stereoplotter was not in digital mapping but in aerial triangulation. There are, admittedly, a number of softcopy stereoplotters, but they have not found wide acceptance because of high costs and the requirement of expensive input-output (I/O) devices. The poor scanning resolution that can be handled by current technology is also another limitation, and to match the resolution of a film diapositive on a softcopy device is not a practical proposition today.

Orthophoto mapping does not suffer from these disadvantage. Manufacturer's prices of orthophoto systems indicate that a digital orthophoto system complete with input scanner and output film-writer is about the same price (or cheaper) than an optical/mechanical system, and the trend obviously will be towards lower prices for the digital system. The most important feature, however, is the fact that a scanning resolution of 1000 dpi or 25 micrometres will produce a resampled orthophoto hardcopy acceptable to the human eye at a six times enlargement, and this resolution with the resultant 30- to 40-mb output file can be processed using the high-end workstations. PC technology, with the enormous compute power available from special boards, will also compete with the high-end workstations (although data transfer rates rather than mips could be a limiting factor).

And how will the digital orthophoto be used? Clearly, it is an ideal base for the updating of existing line maps by displaying old vector mapping data over a new orthophoto image. Perhaps the greatest application, however, will be in the use of the raster image – both aerial photo and SPOT – as a layer in the geographic information system (GIS) of the future.

PRI²SM DESIGN FEATURES

In designing the PRI²SM workstation, the main concern was to build a high-end system that would utilize existing I²S image-processing technology to produce a mapping system that could be used in a production environment. With the large size of the images involved, it was realized that considerable compute and display power would be required. It was also realized that, because of the large amounts of data needed for the production of the orthophoto, the system would have to incorporate a database.

The Air-Photo version of PRI²SM utilizes systems and procedures that were familiar to the photogrammetrist. For example, PRI²SM accepts aerial triangulation data, both photo coordinates and control points. The terminology used is that of photogrammetry, and error analysis is displayed in tabular and vector formats in metric units used by photogrammetrists.

Another design feature was the requirement that the hardcopy output (the orthophoto map) be of a quality acceptable to the photogrammetric community and should be at least equal to that available from traditional hardware. This did pose somewhat of a problem in the early days of building the system in that output filmwriters were fairly expensive. It came as a pleasant surprise, therefore, when the IRIS ink-jet large format plotter was released. Visual inspection showed a more than acceptable image, both to I²S staff and to potential customers, and the price was about 50 percent of the film-writers.

SPOT PRI²SM was first developed as a system for the processing of level 1B imagery (SPOT imagery for which radiometric corrections have been applied and some geometric distortions have been removed). It was realized all along, however, that what was needed was a system that could generate all the SPOT products using precise orbital modeling, and the 1B system has now been superseded by such a system. The SPOT-DEM system has many of the features of Air-Photo-DEM PRI²SM, including the same DEM editing, INGRES database, and quality control.

INPUT/OUTPUT

A major part of any softcopy mapping system is an input scanner. A survey was conducted by I²S of scanning and plotting systems, and it became apparent that scanners were divided into different classes. First of all, there was the desk-top scanner; usually $10,000 to $20,000 in price and scanning mostly in a reflective mode at anything up to 600 dpi. Scanners at a higher resolution (1000 dpi and above) which allowed transmissive scanning of diapositives were much more expensive,

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costing upwards of $50,000. Tests indicated that transmissive scanning was essential to achieve quality imagery. Most desktop scanners could not scan diapositives, and although scanning a print gave a image that appeared acceptable to the eye, closer inspection under a microscope revealed a loss of detail when compared with a transmissive scan image.

The Optronics C4100 SP scanner was selected to be interfaced to the PRI^{2}SM host computer. With a 10- by 10-inch format and a resolution of up to 2000 dpi, it appeared suitable for the scanning of standard aerial film. It was capable of transmissive or reflective scanning, and was a single-pass color scanner. Interfacing was not a simple matter and, therefore, special software had to be written. The interface software displays a subsampled image from a rapid scan for selection of the scanning area of interest. Scanning times are about 25 minutes for a full 1000 dpi scan of a 9- by 9-inch diapositive.

At one time the output posed a problem in that the only suitable large- format output devices were expensive film-writers, costing on the order of $250,000 and above. Subsequently, the IRIS Continuous Color Ink-Jet Plotter (by Scitex) came on the market and, with a format of 32 by 47 inches (E or A0) and a price tag of about half that of the film-writers, it became the natural choice as the PRI^{2}SM large-format hardcopy output device. Being ink-jet, the image could be output onto virtually any type of material. The quality of output was surprisingly good and gave the appearance of good photographic quality. Resolutions of 200, 240, and 300 dpi are available and plotting times are on the order of 30 to 45 minutes for a 25- to 30-mb orthoimage. The IRIS is interfaced directly to PRI^{2}SM, and the user can make use of the IRIS menus for setting up the plot parameters. Pixel replication is available for larger scale plots.

HARDWARE/SOFTWARE

The hardware components of PRI^{2}SM are made up of a host computer (24 mb RAM), 2.6 gb disks, an array processor, a display processor, black-and-white control monitor, color image monitor, and a cartridge tape. Options include a 1/2-inch tape drive, scanner, output plotter, and table digitizer. For SPOT PRI^{2}SM, the tape drive is considered essential. The function of the host computer is to control the entire system and to operate the extensive man-machine interface. Instructions are sometimes passed down to the array processor which has it's own disk and can function independently of the host. It also has a "C" cross compiler for developed programs. All intensive computing such as image resampling and cross-correlation is processed on the array processor.

The display processor and image monitor (1K by 1K – 24 bit color) has smooth single-pixel xy scroll and integer zoom and, therefore, provides a powerful means for displaying images. It is capable of subsampling on the fly and displaying the resultant image of a 9- by 9-inch diapositive as a full 1K by 1K image. Both monitors – the image display and the host monitor – are controlled from a single mouse.

All software is written in "C" under the SUN OS operating system, and SUNVIEW is used for the man-machine interface. Functions from the I^{2}S System 600 image-processing software are used throughout, such as Image Pan, Image Zoom, Image Rotate, and Piecewise OFM.

PRI^{2}SM OPERATIONAL PROCEDURES

AIR-PHOTO PRI^{2}SM

Preliminary Image Processing

The input data are comprised of scanner input data, control points, photo coordinates from aerial triangulation, flight and camera data, elevation data (DEM), map projection information, and parameters defining the orthophoto map sheets. A System

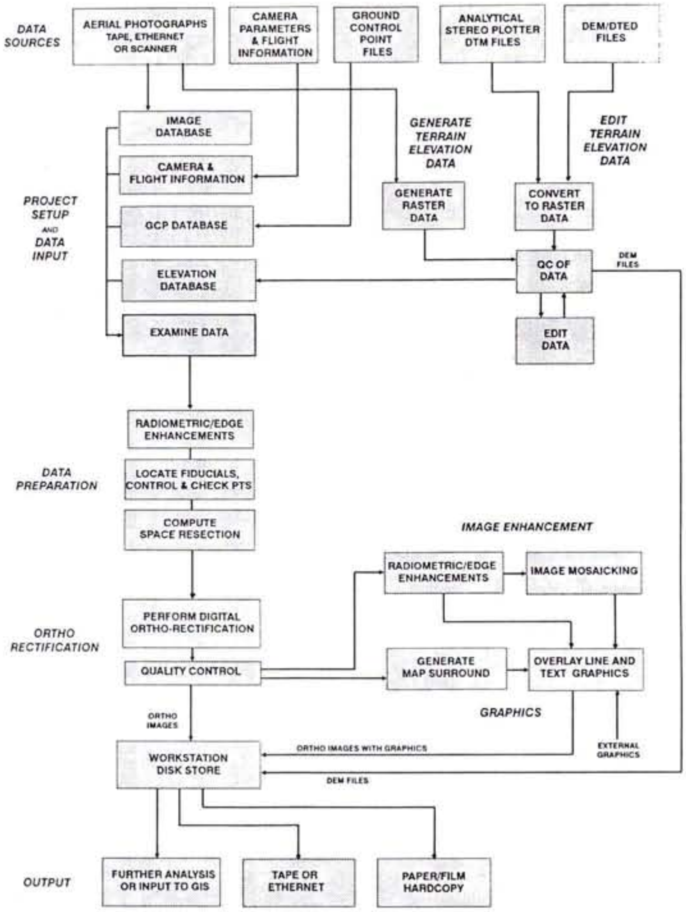

FIG. 1. PRI^{2}SM system organization.

Organization diagram is shown in Figure 1. The scanner data normally come from an on-line scanner which will operate simultaneously with other host computer operations. Image data can also be input from the tape drive. Control either comes from aerial triangulation files (e.g. on-line stereoplotter) or from ground survey or from a table digitizer. If aerial triangulation is available, the measured photo coordinates are input. This allows the system to automatically identify the position of control points on the input image. Camera information is kept in a camera file and is updated each time a new camera is used. Project information is input relating to the flight information (number of lines, flying height, ground height), map sheets, DEM parameters, etc.

The above input data define a project which is the basic unit of data storage. The database constantly tracks data storage and processing, and each new process can only proceed if all relevant data files are available. Most of the computing is done on the array processor, and a Queue Manager window gives information on the current job and the list of jobs awaiting processing.

The first step in processing an image is the inner orientation and picking of the fiducial marks. This is achieved using System 600 software, including pan, zoom, digitize, etc. The control points are then picked (digitized) on the image display monitor. The fast pan and zoom results in simple and rapid control point identification. If aerial triangulation is used, the control point selection can be skipped and photo coordinate positions are then automatically accepted.

The space resection is computed, and plate residuals can be examined either in tabular form or as vectors superimposed on the input image. Full editing capability is available with space resection. A photo-to-ground similarity transformation is also computed, and residuals are displayed as a means of detecting certain errors, for example, the placement of a diapositive upside down in the scanner.

DEM Input Generation and Editing

One of the powerful features of Air-Photo PRI²SM is the handling and processing of DEMs. They can be input from several sources: from stereoplotters (on-line), USGS DEMs from external sources via 1/2-inch magnetic tape, or from a PRI²SM-generated cross-correlation. If the input DEM is not on a suitably oriented regular grid, grid-interpolation is computed on the array processor in a matter of minutes. At this stage it is important to check the coverage of the DEM as lack of coverage seems to be a common cause of an incorrectly rectified digital ortho image. A "check coverage" option allows the operator to display the DEM against a backdrop of the map sheet, and any coverage shortfall is immediately apparent.

If the terrain is suitable, DEMs can be automatically generated using cross- correlation (Srinivasan, 1989). PRI²SM also has options for the generation of epipolar images, although these have not as yet been used for cross-correlation. They are, however, used in the measurement of DEMs on the I²S digital stereoviewer (see below). Cross-correlation is processed on the array processor at the rate of about 20 points per second. A fairly dense network of points is required, and typically 50,000 points will be generated in a stereomodel. When epipolar geometry is used, this figure can be substantially reduced. The cross- correlation area of interest is defined by the selection of control points (monocularly) using a split screen and pan/zoom functions. A gridded DEM is generated in the left-hand photo coordinate system, and a subsequent grid interpolation in the ground system is computed.

The DEM is transformed into a grey-scaled image for editing, i.e., the highest and lowest points are given grey-scale values of 0 and 255, respectively, and intermediate heights are scaled proportionally. This means that image-processing functions can be used for editing and smoothing the DEM data. This is not normally required, for DEMs generated on stereoplotters, which are considered to be error free. DEMs which are captured from digitized contours, or cross-correlated DEMs, would normally be put through the editing process. One of the derived images used in DEM editing is a hill-shaded view. This can be compared with an aerial photo as a first step in the editing process. Individual DEM values can be displayed in table form and edited for spikes. Height values on the ortho-image can be displayed as the cursor roams over the image to provide further quality control (QC) of the DEM.

Ortho-Image Generation – Quality Control – Post Processing

Before any ortho-images are generated, the status of the data is reviewed by the operator. This status window lists all images under Unprepared, Prepared, or Completed. Images are automatically switched between the three classes as each process is completed. At this stage the operator may send a prepared image to the job queue. This places the image in a queue ready for processing by the array processor. Images may be moved around within the queue, and the current job may be interrupted so that a more urgent job can be processed. Ortho-image generation (resampling) can be run overnight by the Queue Manager.

The Queue Manager informs the operator of the completion of an ortho-image, and the image can then go through QC (quality control). At this stage, a summary of all the transformations completed to date can be displayed either in summary form, or by listing each residual, or by displaying residuals in vector form on an image backdrop. This QC is done for the inner orientation (scanner- to-photo) affine transform, space resection (photo-to-ground) projective transform, photo-to-ground similarity transform, and ortho-image check points. The QC stage provides an essential check on the data, and was designed into the system because of the numerous data sets from different sources that go in to the making of the final ortho-image.

Post-Processing is used after the ortho-image generation for a number of image-enhancement techniques available from System 600 software.

Preparing the Map Sheet

Mosaicking of individual ortho-images may be required, particularly for small-scale mapping involving high-flown aerial photography. This function is handled by mosaicking functions within the System 600 software. The two main types are MERGE, which mosaics rectangular images, and MOSAICK, which accepts a random set of points along the boundary. Once the ortho-map is compiled, the map-sheet surround is generated. System 600 software provides a grid function for the gridding of the ortho-image, and a map-surround can be made up using the System 600 graphics. The surround is stored as a "graph file" and can be merged with the ortho-image to form a completed map sheet which can be output to the IRIS plotter or archived to tape. The graph file containing the sheet surround may be recovered for another ortho-image and edited (new sheet number etc.) so that common surround elements are maintained from sheet to sheet.

Digital Stereoviewer

For manual measurement of DEMs, imagery can be resampled to epipolar geometry and viewed through a digital stereoviewer. Each image appears on a small format monitor, and binocular eyepiece is used for viewing. Having zero y-parallax, both images are moved into correspondence on any point and thereafter both images are moved through a constant y shift.

A DEM is defined by the ground coordinates of corner points and grid size in x and y. The system moves to the first grid point and a mouse is used to eliminate x-parallax. The entire grid is stepped through point by point in this fashion. Each monitor displays the image which appears on the PRI²SM image-monitor in split screen mode. When the x-parallax is beyond the range of the human eye, the screen can be repainted after shifting the stereoviewer back into a comfortable viewing position. This manual method is fast, and the DEM so digitized can be merged with a correlated DEM from which a final gridded DEM is interpolated. The manual DEM follows a grid in the epipolar image coordinate system and is interpolated to a ground-oriented grid later.

SPOT PRI²SM – SPOT-DEM PRI²SM

There is considerable overlap between the Air-Photo system and the SPOT system. Some functions are identical – for example, the DEM ėditing – while others are completely different – for example, the mathematical modeling. The project set up is similar to Air-Photo PRI²SM, and the database controls all data by means of projects. Parameters that have to be defined include spectral mode and resampling options such as nearest neighbor, bi-linear, bicubic, and other cubic convolutions. The coverage of the project has to be known to the system, and from this all images covering the area and all control points from a global control point library are listed. As new projects are entered and processed, the database updates the global control point library and the SPOT scene parameters.

SPOT PRI²SM covers the generation of all standard products: 1B (radio- metric corrections have been applied and systematic geometric distortions have been removed), 2A (corrections are applied using only the satellite attitude data – i.e., no ground control is used), 2B (high precision satellite modeling using ground control – the output scene is in a selected map projection), S (the scene is rectified to allow registration with a reference scene), and 3 (a true orthophoto is output).

In addition to the global control point data, SPOT PRI²SM maintains a map library and a chip library. The map library keeps a permanent archive of maps which is controlled by the data base. It is used primarily to speed up the control point selection process. It allows the user to archive the map's characteristics, including the coordinates of the map corners. These are correlated with the control point data and with any digitized data from xy digitized maps.

The chip library is a set of 32- by 32-pixel patches which are automatically selected from an image. These chips are used for future image-to-image registration and are permanently stored in the database.

It is planned to add a second type of chip – control point chips which will be abstracted from an image each time a control point is picked. These will be permanently stored in the database and will be used for future processing of new scenes where the control patches are correlated with the same patches on the new imagery. Thus, control selection only has to be done once for a given area.

As with the Air-Photo PRI²SM system, control points may be selected from two images by a monocular pointing to a split screen. these points can be tie points, control points, check points, or registration points.

Cross-correlation has been tried on six or so SPOT images with a resultant point failure rate of less than 1 percent. This is probably because the image has a uniform appearance (due to the height of the satellite) and is not affected by individual or man-made features. Processing rates vary from 17 to 25 points per second. In order to improve the correlation process, one image of a stereo-pair is rotated into parallelism with the second using two common tie points.

PRI²SM PERFORMANCE – ACCURACY AND SPEED

AIR-PHOTO PRI²SM

The following accuracy test results were achieved on 1:3000-scale aerial photography on open featureless terrain (Table 1). The residuals are differences between *XYZ* coordinates of PUG points read from the Alpha 2000 first-order analytical stereoplotter and *XYZ* coordinates read from a digital ortho-image displayed on a PRI²SM image-monitor. The PRI²SM Z values were generated from a cross-correlation computation. Most of the rejected Z points occurred in the areas of poor photographic image quality.

In addition to the above test, a number of selected models from production data sets have been processed at I²S. The *XY* accuracy on check points from these was consistently in the region of 1 pixel, and this is confirmed by the above test. The reader should note that on the above test the basis of comparison was values read in a stereoplotter and not absolute values from a ground survey.

TABLE 1. TEST RESULTS

Photo Scale	1:3000
Number of models	3
Number of check points	37
Planimetric RMSE	$X = \pm 0.28$ feet
	$Y = \pm 0.39$ feet
Height RMSE	$Z = \pm 0.33$ feet (7 points rejected)
Image Quality	Mostly good but poor in places
One pixel = 0.25 feet = 25 micrometre scan	

The height accuracy was considered satisfactory, taking into account the poor image-quality in certain areas. One of the diapositives appeared quite "fuzzy," and the operator commented on this in his notes taken during the observations.

The speed of PRI²SM is mainly governed by the resampling speed of the array processor. For ortho-image resampling using a rigorous projective transformation for every pixel, processing is at the rate of 2 mb per minute. Thus, a 24- by 30-inch output ortho-image at 200 dpi, giving an image size of 28.8 mb, can be rectified in less than 15 minutes. This could of course be significantly improved by selecting a simplified algorithm (say a bilinear interpolation) operating on image-tiles. The throughput of PRI²SM is higher than the above time might suggest because the ortho-image resampling is done in a background mode on the array processor, simultaneously with other production tasks on the host CPU.

SPOT PRI²SM

Accuracy tests were carried out on data obtained from SSC Satimage, Kiruna, Sweden. The data comprise a SPOT (Pan.) level 1A scene with 20 ground control points and a 10 m pixel size. Residuals at check points were computed in the output space yielding the following sub-pixel planimetric RMSEs:

Control	Checks	RMSE (Checks)
3	17	± 5.75 metres
10	10	± 4.28 metres

The following times are for resampling at level 2 in seconds per megabyte for panchromatic (pan) and three-band color (XS) images:

Device	Elapsed Time	Compute Time
Array Proc. (pan)	17.0	13.3
Array Proc. (XS)	17.1	13.4
CPU (pan)	201.3	199.4

The large difference between the array processor and the CPU attests to the high speed of the former.

FUTURE DEVELOPMENT

During the next ten years photogrammetry will undoubtedly undergo a profound transformation – high-precision optical/mechanical instruments will be gradually replaced by the computer. The film image will be scanned and a raster image used as the basis of measurement. Some images may be available directly from a digital camera. This trend has already begun and the PRI²SM workstation – Air-Photo and SPOT - is one of a number of systems now coming onto the market servicing this area.

This raster-based technology appears to offer cheaper and faster production and greater variety in data output products. New developments in voice-recognition, three-dimensional viewing systems, and knowledge-based systems will also be used in the development of digital photogrammetric systems. One can also envisage a broadening of the user base for photogrammetric systems using low-cost PC/workstation-based digital stereoplotters mapping from a digital ortho-image base. Photogrammetry now appears to be entering into a most exciting phase of development, a phase which was not anticipated by many, and which will see an increased pace of development as the storage capacity and speed of computers increases.

REFERENCES

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