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Instrumentation for topographic mapping from satellite data

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Introduction

The past ten years have seen a great increase in the use of data derived from sensors on board satellites for topographic mapping; many papers have been written which investigate the geometric conditions and the accuracy which is to be expected. So far very little data with real potential has been produced and little attention has been paid to the methods of plotting, particularly when using stereoscopic images. Only certain types of image can be used in conventional plotting instruments and the problems of using digital data have barely been tackled at all. Some proposals have been made for automatic mapping systems but there are questions hanging over the implementation of such systems which must be answered.

This paper is concerned with topographic mapping of plan and height at 1:100 000 scale or larger. The paper will not therefore consider Landsat data but will confine itself to photographic systems, push broom systems and briefly, with radar. After an initial section on the data, discussion will centre on instrumentation which is relevant to the data.

Sensors

The characteristics of the most important sensors are given in Table 1. The primary form of data from a photographic system is a negative which contains all the information recorded of a single scene, by the camera. The main variables when considering methods of plotting are the principal distance of the camera and the format size. If the oblique photographs are involved then the amount of tilt is relevant.

The geometry of a camera is characterised by the collinearity equations which represent straight lines joining points on the surface of the earth to the image points on the negative. A perspective bundle of such lines may be reconstructed in an analogue instrument by a mechanical rod or height rays and analytically by the collinearity equations. Any deviations of the imaging ray from a straight line must be accounted for. As a complete scene is imaged at one time, any reconstruction is independent of time.

At present there are three photographic systems which should be considered as indicated in table 1. The metric camera on Spacelab is described by Schroeder (1982), Ducher (1980), the large format camera by Doyle (1982) and the MKF-6m by Zickler (1977).

In March 1984 photography is available from the metric camera, the large format camera will be used during 1984. It is expected that both these cameras will be used again in future years. The MKF camera has been used on several Soyuz missions and on the Salyut space laboratory.

The push broom systems are expected to become the standard satellites for continuous earth observation giving high resolution, stereoscopic cover. The collinearity equations also represent the geometry of a push broom sensor but the position and attitude parameters are constant only for recording a single line of data, thus to determine them with the aid of

Table 1 Summary of data from space suitable for topographic mapping

Sensor	Primary form of data	Size of standard scene	Type of transformation
Photographic		(H = 250km)	Solution of collinearity equations using ground control with space intersection for third dimension
Metric Camera (Zeiss RMK 30/23	Photograph 230 x 230mm	188 x 188km	
Large Format Camera	Photograph 460 x 230mm	376 x 188km	
Zeiss MKF-6M	6 multispectral photos each 55 x 80mm	110 x 160km	
Push broom	Digital		Orbit parameters plus use of collinearity equations, ground control and space intersection.
SPOT	6000 sensors/line	60 x 60km	
MOMS	6912 sensors/line	-	
STEREO MOMS	-	-	
MAPSAT	18000 sensors/line	180 x 160km	

ground control, time dependent collinearity equations must be used and linear or polynomial constraints must be used to link the successive sensor positions.

SPOT will be launched in 1985 (Chevrel et al 1981) and already a great deal of work has been done on simulated SPOT data. MOMS (Bodechtel 1983) has already been flown on Shuttle Transport System (STS) mission no.7 on the free flying space platform SPAS. Stereo MOMS is being developed together with a software system to map from the data (Hofmann et al 1982). The Mapsat concept has been described by Colvocorresses (1982) and this includes automated mapping. The Canadian Centre for Remote Sensing has developed an airborne push broom system MEIS which is being developed to obtain stereo image (Neville 1983) and this should be considered as a future source of data.

At present synthetic aperture radar (SAR) cannot be considered as a serious source of data topographic mapping because of poor resolution and complex distortion. However, some stereoscopic was obtained from Seasat and there is considerable interest in the Shuttle Imaging Radar (SIR) already flown on STS2 and to be flown again on STS17 A European microwave satellite ERS1 will be launched in the late 1980's. Details of these systems and of the geometry of radar can be found in Allan (1983) and Leberl (1976).

Control

An essential element in using any data for topographic mapping is the determination of the elements of exterior orientation. The number of elements required is six for a single photograph. With push broom sensors six elements are needed for each line of data since the satellite will have moved between recording each line. The number of unknowns to be found is reduced by relating successive perspective centres and attitudes by linear or non-linear functions.

Existing earth observation satellites cannot be fixed in position and attitude with a sufficient degree of accuracy to provide the elements of exterior orientation and therefore ground control must be used. The provision of ground control in the traditional manner is an essential part of mapping from metric camera photography and will be from SPOT data.

It is argued that much of the value of mapping from satellite data is lost if control has to be fixed on the ground, therefore with several new systems, provision is made for the determination of the elements of exterior orientation by on board sensors. The requirements for the accuracy of such systems are discussed by Welch and Marko (1981), Colvocoresses (1982) and Doyle (1982) and it is concluded that position is required to better than 5m and attitude to better than 5" with changes in attitude measured to 10^{-6} deg sec^{-1}.

The means of acquiring the position and attitude of the satellite are the Global Positioning System (GPS) which will give position to 7m in X, 7m in Y and 10m in Z, and star cameras giving attitude to 5" or electro optical stellar sensors to 2". A combination of these methods is proposed for the large format camera on STS-17 (Doyle 1982) and for Mapsat (Colvocoresses 1982). Such systems are not yet proven and it seems likely that some ground control will be needed for some considerable time yet.

Analogue plotting instruments

A significant advantage of photographic sensors is that the photographs can be used in some existing photogrammetric plotting instruments. There are however limitations. Images from non photographic systems cannot be used without extensive processing and correction.

The image on a photograph taken from around 250km above the surface of the earth will be of the curved surface of the earth and will be subject to distortion due to refraction and to any effect of using a camera window. It is usually desirable to plot a map on a particular map projection and therefore to compensate for the image of the curved earth on the photograph by changing x and y parallax or by changing the model co-ordinates. Radial compensation of 0.6mm in the corner of a photograph is required in the case of a metric camera photograph. The effect of refraction will be very small because of the use of a normal angle lens. Meier (1974) has investigated the effect of temperature and pressure changes across a camera window and distortion may reach 40μm in any radial direction, however Zeiss (personal communications) expect the camera window on Spacelab to have no effect because the camera principal distance has been changed to compensate.
In order to use analogue instruments it must be possible to allow for these effects in an instrument which will accept the camera principal distance and format size. The metric camera and the large format camera have principal distances of 305mm and the images can therefore by accommodated in many plotting instruments, only the centre of the large format camera image will fit into a 230 x 230mm plate holder and, whilst plotting can be carried out from such a reduced image, the advantages of the wide angle base:height ratio are lost.

The combined effect of earth curvature, refraction and camera window will be to create a distorted model, this may be corrected by analogue devices but their precise effect should be investigated before correction is assumed. In the absence of any correction, co-ordinates may be recorded in the model space in an XYZ system and if ground control co-ordinates are known in a geocentric co-ordinates system, a model may be set up and recorded co-ordinates transformed to a required projection.

A typical analogue correction device will apply a displacement radial to the nadir thus creating a projection on a plane which is tangent to the surface of the earth at the nadir point. If the altitude of the camera was 250km, this projection has a scale error of 0.9976, 100mm from the nadir at photograph scale; when referred to a Transverse Mercator projection on which scale is correct along the central meridian, a differential scale error is created, which, if distributed over the model would be a maximum of 0.9988. This effect can be reduced by scaling to control over a small area.

The radial correction is normally computed by assuming that the point to be considered is on the surface of a sphere. If relief is present this is no longer correct and can cause errors in height of 10m with relief of 500m.

Before using any analogue correction device it is necessary to determine the precise effect of the system and to analyse the errors at control points before proceding to map compilation. Clearly the distribution of control is also critical.

There are a few analogue instruments on the market which will allow restitution of metric camera photography. The Wild A10, AMU, AMH and AM stereo plotter may have correction devices fitted. The Stereometrograph of Zeiss Jena can accommodate normal angle photographs and has a model correction device which allows correction to Z for height but which may leave residual plan errors after absolute orientation. The Carl Zeiss Planimat also accepts normal angle photographs and an optional earth correction device is available.

There are other plotting instruments which must be considered as suitable for plotting from space imagery: these are stereocompilers which will allow a planimetric plot to be prepared by direct or enlarged tracing from an orthophotograph whilst viewing stereoscopically with another photograph. Contours can be plotted if the second photograph is rectified for the effects of tilt and earth curvature. The Ortoster instrument developed by IGN (France) is one such instrument and the Cartographic Engineering CPl can be modified to carry out the same task. Data from SPOT in photographic form can be plotted in this way using a level 3 product (an orthophotograph) together with a level 2 oblique or a level 1B oblique corrected by the correction system of the CPl. Baudoin and Lestringand (1981) and Dowman and Gugan (1984) report on this method of plotting.

Analytical stereo plotting instruments

All of the limitations on plotting from photographs in analogue instruments can be overcome when using analytical instruments. It should not however be assumed that this can be done using the manufacturers standard software. The same limitations will apply as discussed in the previous section if radial correction for earth curvature is applied.

The flexibility of the analytical plotter can be used to extract the maximum accuracy from the instrument. A rigorous approach is to reconstruct the perspective bundle in the plate processor by using a radial correction for refraction and hece derive model co-ordinates in a rectangular geocentric co-ordinate system. Ground control points would need to be input in such a system for setting up purposes. For plotting, the geocentric co-ordinates must be converted to projection co-ordinates; a rigorous procedure for this involves the intermediate step of determining latitude and longitude but investigation is needed into a more direct method of doing that conversion.

Photographic images of push broom data can also be used in an analytical plotter. The geometry of the push broom system requires the programming of the plate processor to accommodate each perspective pencil; it is clearly impossible to store the exterior orientation elements of all perspective centre positions so some interpolation is required. At IGN (France) a method developed by Masson d'Autume (Ducher 1980) is used whereby a deformation model is computed giving XYZ ground co-ordinates of image points on a grid pattern. Plotting is then done by real time interpolation. Such a method can be used to derive a digital elevation model for orthophotograph construction.

The elements of exterior orientation can be found with regard to the considerations discussed under ground control above and at present would be found using time dependent collinearity equations.

Radar images can also be set up in an analytical stereo plotter. Leberl has done this with a Kern DSR1 but the ISI-11 plate processor cannot handle the real time task rapidly enough and a faster processor is needed to ensure movement of the images without delay.

Digital compilation

Most data for earth observation from satellites is recorded in digital form and it is therefore sensible to use it in that form but bridgigg the gap between the stereoscopic line following capabilities of systems using photographic imates and those of digital systems presents a great challenge to the system designer.

When considering the requirements for a suitable instrument the differences in scale and coverage between aircraft and satellite data must be noted. Aircraft photography is usually on a format of 230 x 230mm at a scale of less than 1:100 000; data from a satellite will not be defined by format and scale but by the number and size of pixels in a scene of fixed width but arbitary length. In order to determine the elements of exterior orientation the area considered should be large but the plotting area need be only a part of the full scene, enough to cover a map sheet for example. There are therefore two requirements; first to be able to identify control points over a wide area necessitating the capability to rapidly scan a complete scene but to look in detail at only small parts of it and, second to scan and plot a limited area.

The operator needs to view a display in which pixel edges are not visible and which covers a convenient area. If a pixel size of 10m is assumed and a map scale of 1:50 000 then a field of view of 512 x 512 pixels with the ability to zoom to greater magnification should be adequate. A 512 x 512 view could be accessed in two ways; it could be part of a larger scene over which the operator is roaming with a fixed cursor or could be a sub scene over which the cursor can be guided. The former could be a whole scene at reduced resolution, that is for example only every 5th pixel displayed, or it could be a sub scene at full resolution, the latter could be a patch within which a control point is located.

The system can therefore be specified in the following manner: a complete scene is to be displayed and scanned at reduced resolution, patches of that scene to be accessed and viewed at full resolution or a subscene to be specified and displayed at full resolution in a mode from which line data can be extracted. Considering the quantity of data involved and the access time a scene from SPOT can be taken as an example. Two scenes 60km x 60km will provide stereoscopic overlap, each scene contains 6000 x 6000 pixels and one full scene could be contained within 1024 x 1024 pixels at one sixth resolution. Control point patches could be contained within 256 x 256 pixels and a convenient sub scene for plotting, covering 10km x 10km would contain 1000 x 1000 pixels. A scheme for such a system is given in figure 1.

The requirements set out in the previous paragraph can be met by existing technology. An I^2S digital image processor for example with 12 frame stores could contain all the necessary data with real time access. If the operation was considered in two stages, orientation and plotting, then with 12 frame stores, a one sixth resolution image and 32 control point patches could be stored and subsequently be replaced by a 15 x 20km sub scene for plotting.

Case (1982) sets out a specification for an instrument for digital plotting from aerial photographs, he assumes a digitisation level of 10μm over a 230 x 230mm photograph and a scanning speed of 2.5mm sec^{-1}, this is a

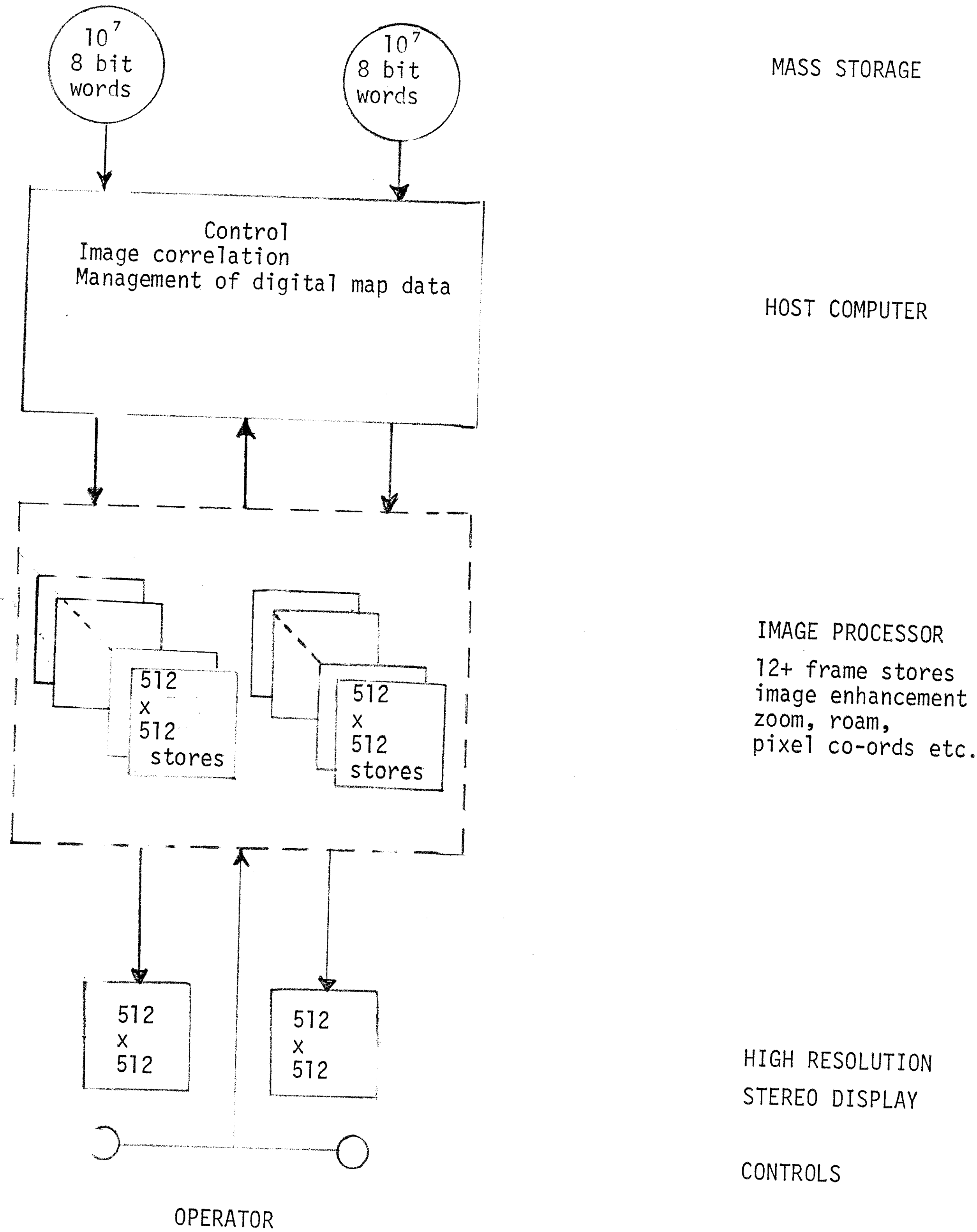

Figure 1 SCHEMATIC DIAGRAM OF DIGITAL STEREO COMPILER

higher requirement than the one specified here. It is of course to be expected that a system designed for map compilation would be more suited to that task than an existing system designed for image analysis. If the full potential of digital image processing is exploited, including enhancement and use of multispectral data, then again the specification would be more demanding.

The main hardware requirements are mass storage devices, storage with real time access and display. Mass storage for scenes containing 10^7 pixels or more will probably be provided by optical discs. Tests are already going on into the use of this medium for storing images. 1024 x 1024 frame stores would be ideal for real time access but mosaicing of 512 x 512 stores can be used very efficiently. A requirement not fully investigated is that for high quality stereoscopic display. Single displays of sufficient resolution exist and stereo displays have been used, for example by Real (1982) and Boyde and Ross (1975). More recently Bedwell (1980) has investigated the use of two screens for stereo viewing of photographs, and Petrie (personal communication) is investigating a dual screen flicker system. Split screen polarised systems and anaglyph systems are also possible.

A number of proposals have been made for the use of digital systems for map compilation and work is going on to develop such systems. Case (1982) has proposed a digital stereo comparator/compiler (DSCC) which is designed to use automatic correlation of all points using digital imagery. Whilst being designed for central perspective images, the concept is applicable to any geometry. Colvocoresses (1982) has proposed an automatic compilation system for use with Mapsat data, utilising epipolar lines of data which are recorded by the satellite under constant guidance. At the ITC an interactive digital restitution system is being developed and at University College London proposals along the lines of those discussed above are being investigated.

Conclusions

It has been shown that existing equipment can be used to produce maps from data acquired in space, however in all cases the methods available must be carefully analysed and assessed as regards their suitability for the specific data. Analytical stereo plotting instruments appear to have the greatest potential when using hard copy images and examples are given of their application. Work is going on in several centres to develop the use of digital imagery and the technology exists to develop such instruments but it is to be expected that different instrumentation and method will be used for different types of image and the next four years will provide interesting developments in this field.

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