POTENTIAL OF LINEAR ARRAY SCANNERS FOR MAPPING APPLICATIONS

Ahmed M. Amin
UAE University

ABSTRACT

The use of Charge Coupled Devices (CCD) arranged in a linear array is becoming the main technology in imaging the earth's surface from space. This paper describes and evaluates two systems employing this technology, the German system (MOMS) and the French system (SPOT). The paper investigates the possible use of the image obtained by the two systems for mapping applications. Geometrical analysis and rectification supported by a case study are presented.

Keywords: CCD, Spot, MOMS, Analytical photogrammetry, Mapping.

INTRODUCTION

During the last few years, the attention of the topographic mapping community was directed towards the possibilities of mapping from space imagery and in particular towards the development and implementation of solid state arrays as a replacement of mechanical scanners in space. Those solid state detectors may be arranged either in a matrix form (aerial array) or in a linear form. In the former case, the image of the ground sense is recorded so that for each ground pixel across the frame the will be a corresponding CCD element on the focal plane of the scanning system. Although these systems are still recognised as scanners they do not contain any scanning process and in fact the geometric fidelity of the image obtained by aerial array scanners are comparable to that obtained by the metric frame camera since the whole image of the ground scene (frame) is recorded instantaneously and with central projection method.

One the other hand, linear scanners simultaneously image a complete narrow strip of the terrain (scan line with one pixel width and the ground coverage is produced by the platform forward motion. The image of the ground line across the flight direction is focused on the focal plane of the system where a raw of CCDs are arranged so that for each ground pixel there is a corresponding CCD element as shown in Figure (1).

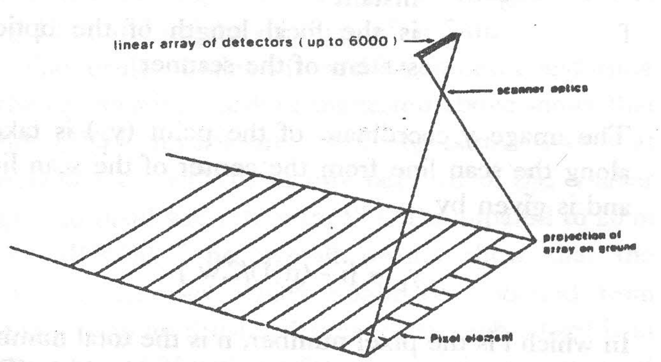

Figure 1. Arrangement for linear array scanners.

ANALYTICAL PHOTOGRAMMETRY FOR LINEAR ARRAY SCANNERS

The scanning technique adopted by the linear array scanners result in an image which is built up line by line with each line size limited by the pixel width and the number of pixels per line. Hence, one set of collinearity equations relates all image points within this scan line to their corresponding ground points. AT the platform moves in its orbit orientation elements continuously vary with time, therefore a new set of collinearity equations is needed for each scan line. In general, the collinearity equations can be written in the following form to accommodate this dynamic nature of the image:

$$O=-f\frac{m_{11s}(x_p-x_{os})+m_{12s}(y_p-y_{os})+m_{13s}(z_p-z_{os})}{m_{31s}(x_p-x_{os})+m_{32s}(y_p-y_{os})+m_{33s}(z_p-z_{os})} \quad (1)$$

$$y_p=-f\frac{m_{21s}(x_p-x_{os})+m_{22s}(y_p-y_{os})+m_{23s}(z_p-z_{os})}{m_{31s}(x_p-x_{os})+m_{32s}(y_p-y_{os})+m_{33s}(z_p-z_{os})} \quad (2)$$

Where:

x_p, y_p and z_p	are the ground coordinates of any point p which is imaged on scan line s
x_{os}, y_{os} and z_{os}	are the coordinates of the projection centre at the instant of imaging scan line s expressed in the terrain coordinate system
m_{11} to m_{33}	are the elements of the rotation matrix which express the orientation of the platform at that instant
f	is the focal length of the optical system of the scanner

The image y coordinate of the point (y_p) is taken along the scan line from the center of the scan line and is given by

$$y_p = \{i - (n-1)/2.w\}$$

In which i is the pixel number, n is the total number of pixels in the array and w is the pixel width. The image x coordinate of any point on the scan line is taken to be equal to zero since only a single scan line is considered in these equations.

Since the scanner is loaded on a satellite which moves in space, it is likely to be more stable than the case of the camera loaded on aircraft which means that the changes in the orientation parameters will be very small. However to account for these small changes and for the errors expected in the interior orientation parameters (the system is not calibrated since it was not designed for mapping purposes), it is suggested to implement a resection intersection technique with additional parameters used to model and correct for any errors expected in the final derived three dimensional ground coordinates.

This solution is based on adding specific parameters to the collinearity equations to compromise for the effect of changes in the exterior orientation parameters as a result of the adopted scanning technique.

The following polynomial equations will be tested and the ineffective terms will be truncated from the model by trail and error until a fixed formulae would be obtained.

$$x' = a_o + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 \quad (3)$$
$$y' = a_o + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2 \quad (4)$$

Where x', y' are the corrected image coordinates and x,y are the measured coordinates. It is obvious that the use of this method would require more control points to solve for the correction parameters as well as for the exterior orientation parameters. This model contains 12 unknowns (a_o to a_5 + b_o to b_5) therefore a total number of 18 unknown parameters (these 12 plus the normal 6 parameters of the exterior orientation) have to be determined for an individual image during the space resection phase. Since each control point (with known X, Y and Z coordinates) gives rise to two equations, a minimum number of 9 control points is required to solve for the unknown parameters for a single frame scanner image. If more than 9 point are used, then the least squares technique must be used.

This method is applied by performing a conventional space resection to solve simultaneously for the six orientation parameters together with the additional parameters. The additional parameters are used to correct the measured image coordinates of the check points. These corrected coordinates are then used in the space intersection phase in the normal way.

MOMS SENSOR SYSTEM AND EXPERIMENT

One of the system employing linear array technology is the Modular Optoelectronic Multispectral Scanner (MOMS) developed by Messerschmitt-Bolkow for the west German ministry of defence. The detector elements in the scanner arrays are CCD with 1728 pixels per array. The geometric parameters of this system are shown in Table (1).

Table 1. MOMS Geometric Parameters.

Sensor	reaction ccpd 1728	Ground pixels/line	6912
CCDs/line	4	channel 1	λ=.575 to. 625μm
Altitude	300 km	channel 2	λ=.825 to. 975μm
pixel size	16 μmx16μm	total field of view	26.2°
ground pixel size	20m	swath width	138 km

SPOT SYSTEM EXPERIMENT

The "system Probatoire d' observation de la terr" (SPOT) is another system employing the linear array technology. The system was designed by the French Centre National d' Etudes Spatiales (CNES) SPOT-1 was launched on 22nd February 1986 into a sun-synchronous, near polar (98.77° inclination) orbit at an altitude of 832 km. The system consists of two identical High Resolution Visible (HRV) imaging sensors each of which contains 4 subarrays of CCDs A 6000 element subarray is used for panchromatic mode giving 10 m ground pixel size, and a 3000 element subarry is used for the multispectral mode resulting in a 20 m ground pixel size. In the panchromatic mode the system operates in a broad wavelength (λ=0.51 μm to 0.73μm) while in the MSS mode on three narrow wavebands (λ=0.50 μ m to 0.59μm-λ=0.61 μm to 0.68 μm-λ=0.79 μm to 0.89 μm). The light rays from the ground scene which is being imaged enter the HRV via a plane mirror that is steerable by ground control to view the ground scene in either side of the ground track with a maximum tilt angle of 27° relative to the vertical. This capability allows off nadir viewing in addition to the nadir viewing which makes it possible to acquire stereoscopic imagery with a large base to height ratio.

Practical Test

The analytical photogrammetric approach discussed above was tested using two MOMS scenes and two Spot-1 panchromatic scenes. The test procedure was carried out by measuring the photo coordinates of some selected well defined points from the images. The central scan line was selected as the x-photo coordinate system while the mid-point of this line was taken as the origin of the photo coordinate systems (no fiducial marks on the scanner images). The photo coordinates were measured using a Stecometer monocomparator. The ground coordinates of the selected points were digitised off the 1: 100,000 scale map covering the area using a Sumagraphic digitiser with a planimetric accuracy of $\pm$ 10 m and height accuracy of $\pm$ 5 m.

The results obtained from this geometric test using the rectification method suggested above shows that the SPOT results are relatively better than that obtained by MOMS mainly because of the smaller ground pixel size (10 m for SPOT compared to 20 m for MOMS). The overall results show that the average accuracy which might be obtained from images acquired using Linear array technology is in the range of 25 to 35 m for planimetric accuracy and 15 to 20 m for height accuracy.

The geometric parameters and accuracy figures obtained in the current investigation must be compared to standard specifications of small scale maps. These specifications were summarised by Doyle (1984) as shown in the table below:

Those figures were made assuming that the images are of high geometric quality such as metric frame camera. Comparing the figures obtained in this test with those of standard 1:100,000 scale figures it can be seen that the test figures are much higher than standard figures, they may be rather used for the 1:250,000 scale mapping with relaxation in the height accuracy.

Table 2. MOMS Test Results

Technique	Control Points (18 points)				Check Points (24 points)			
	δ_N	δ_E	δ_V	δ_Z	δ_N	δ_E	δ_V	δ_Z
Conventional Res./Intersection (no additional parameters)	35.1	33.2	47.6	29.3	39.4	39.6	55.8	35.2
$x' = a_o + a_1 x + a_2 y$ $y' = b_o + b_1 x + b_2 y$	26.8	25.3	37.3	15.4	32.5	31.1	44.9	17
$x' = a_o + a_1 x + a_2 y + a_3 xy$ $x' = b_o + b_1 x + b_2 y + b_3 xy$	26.8	25.1	36.7	15.1	31.8	32.6	45.5	16.7
$x' = a_o + a_1 x + a_2 y + a_3 xy + a_4 x^2$ $x' = b_o + b_1 x + b_2 y + b_3 xy + b_4 x^2$	25.9	24.8	35.5	14.5	29.8	30.6	42.7	16.1
$x' = a_o + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2$ $x' = b_o + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2$	25.8	24.9	35.8	14.5	29.6	30.7	42.6	16.9

Table 3. SPOT Geometric Test Results

Technique	Control Points (18 points)				Check Points (24 points)			
	δ_N	δ_E	δ_V	δ_Z	δ_N	δ_E	δ_V	δ_Z
Conventional Res./Intersection (no additional parameters)	31.7	26.2	41.1	25.4	35.3	30.2	46.4	27.5
$x' = a_o + a_1 x + a_2 y$ $y' = b_o + b_1 x + b_2 y$	22.3	21.5	30.9	15.6	24.3	24.5	34.4	15.6
$x' = a_o + a_1 x + a_2 y + a_3 xy$ $x' = b_o + b_1 x + b_2 y + b_3 xy$	22.5	20.4	30.4	15.3	24.8	21.5	32.8	15.7
$x' = a_o + a_1 x + a_2 y + a_3 xy + a_4 x^2$ $x' = b_o + b_1 x + b_2 y + b_3 xy + b_4 x^2$	22.2	20.8	30.4	15.4	24.5	21.6	31.4	15.9
$x' = a_o + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2$ $x' = b_o + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2$	20.1	20.3	28.5	14.6	24.9	20.9	32.5	15.7

Table 4. Standard specifications for small scale maps

Scale No.	Contour interval	Contour accuracy	Planimetric accuracy	Spot height accuracy	Ground resolution
500,000	50	17	150	15	29
250,000	25	8.5	75	8	14
100,000	20	6.8	30	6	6
50,000	10	3	15	3	3

CONCLUSION

The geometric tests conducted in this research work showed that the positional accuracy figures of maps which might be generated from linear array scanners are not satisfactory for the 1:100,000 scale maps but they are very close to that of the 1:250,000 scale. However the results in this test may be improved if more than one model from each scanner was used and also if the image coordinates were measured stereoscopically. But these facilities were not available during the time of conducting this research. Nevertheless, this research has proposed a new criteria for the photogrammetric rectification of linear array scanners.

REFERENCES

[1] A.M. Amin and G. Petrie, "Design Characteristics and Geometric Calibration of Video Frame Scanners", ISPRS Journal of Photogrammetry and Remote Sensing, vol. 49, No. 1, pp. 12-24, 1994.

[2] F.J. Doyle, "Surveying and mapping with space data", ITC publication, Series A, vol. 4, No. 3, pp. 14-32, 1984.

[3] K. Jacobson, "Experience with space photographs for mapping", Proc. of the international scientific cooloquium {use of space photographic data for mapping of earh-surface", ISPRS working group I/II leipzig, pp. 1-137, 1977.

[4] G. Konency, "Mathematical models and procedures for the geometric restitution of remote sensing", Proceedings of the 13 th international congress of photogrammetry ISP, Helsinki, International archives of photogrammetry, vol. 21, No. 3, 11 pages, 1974.

[5] G. Petrie"Mapping from earth satellites", Proceedings of PTRC summer annual meeting, University of Warwick, paper No. 9, 1974.