14TH CONGRESS OF THE INTERNATIONAL SOCIETY OF PHOTOGRAMMETRY

HAMBURG, 1980

Commission III WG III-1

Presented paper.

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PHOTOGRAMMETRIC APPLICATIONS OF LANDSAT MSS IMAGERY

Introduction

Resolution and geometric accuracy are the main factors limiting the cartographic applications of available space imagery: for Landsat MSS imagery the major weakness is its resolution. With the new systems planned for the early 1980's such as SPOT, Landsat D and the metric camera experiment on Spacelab, these limitations and weaknesses will be reduced, therefore better understanding of the geometric distortion and the potential for rectification of the presently available systems will help bring quick and successful implementation of the imagery from the new systems.

This paper summarises some results of research carried out at University College London aimed at developing new mathematical techniques and at modifying the conventional ones to rectify MSS imagery. Another purpose of this work is to test the possibility of obtaining height information from Landsat MSS images and to check the possibility of using these images for topographic mapping, map revision and thematic mapping.

Data and observation

All images used were of the United Kingdom. Five band 6 1:1 000 000 frames were used, three supplied by Telespazio from Fucino (Nos. 218-22, 219-22, 220-22) and two (221-21 and 220-21) supplied by the U.K. National Point of Contact (NPOC) at Farnborough, these two were image enhanced. Two system corrected MSS CCTs were also used (217-24, 212-20).

All ground control information was obtained from Ordnance Survey 1:50 000 topographic maps. Heights were obtained by interpolation between contour lines with an accuracy of about ±10 m and plan control points were scaled off with the aid of a pantograph giving an accuracy of about ±15 m.

Image co-ordinates were measured on a Hilger and Watts stereo comparator and the standard deviation of all observations using three rounds to each point was ±20 μm at image scale. This represents 20 m or .25 of a pixel on the ground.

Identification of a sufficient number of ground control points with reasonable accuracy represents an important part of any good geometric analysis. Certain ground features represent a very good choice, amongst them are small water bodies, airfields, highway and railway intersections, woodland corners and boundaries between water and land. On the photographic images suitable points were identified when the photographs were set up in the stereocomparator but when digital data were used a simple map with 9 grey levels was produced on the line printer of the IBM 360 computer. The pixel relating to a control point was fixed by the scan line number and the pixel number within that line. An example of this is shown in Figure 1.

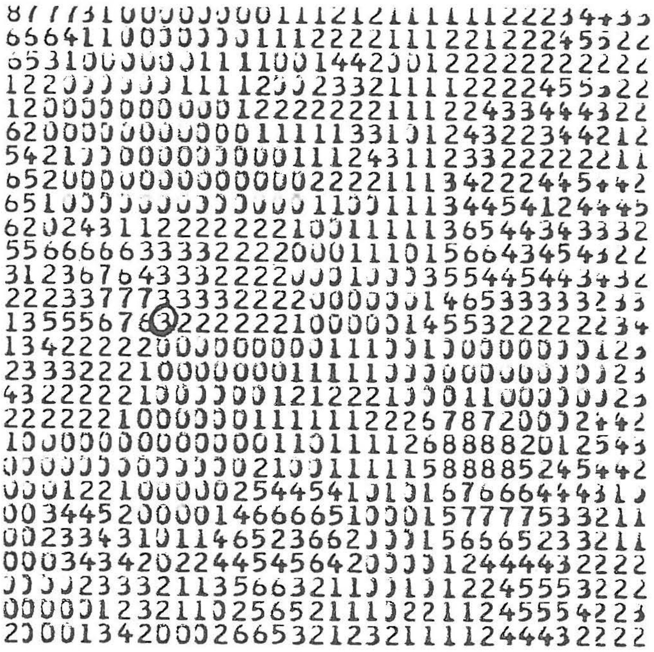

Figure 1. Part of nine class map produced to identify ground control points from digital imagery. Water is class 0; woodland is classes 1 and 2.

Geometrical analysis

Geometrical analysis using similar methods to workers such as Bähr (1978), Steiner and Kirby (1977) and Wong (1975) was carried out by fitting photographic and digital MSS images to ground control by means of different mathematical models. Analysis of residuals for each mathematical model and for different control configurations will define geometric distortions in these images and will determine the best mathematical model and the minimum control required for achieving a given geometrical accuracy within the system capability. The following mathematical models were tested:

- Two dimensional similarity transformation (4 parameters).
- Two dimensional affine transformation (6 parameters).
- Second order polynomials (12 parameters).
- Collinearity equations.

The affine transformation corrects first order distortions such as non-orthogonality, scale difference between along-track and scan directions which may be caused by earth rotation and map projection. In addition, to correct first order distortions caused by tilt and altitude variations second order polynomials may be used. Collinearity equations enable us to take into account variations of the satellite attitude with time, for this purpose polynomials were used to model the sensor's behaviour along the flight path.

With Landsat MSS imagery, as it is with high altitude photography, care should be taken to allow for the correlation between ϕ and X_c and between ω and Y_c particularly in flat areas. This was done by excluding either X_c or ϕ and Y_c or ω and considering the other four elements of exterior

TABLE 1. Root mean square errors in metres at ground scale derived from residuals at check points for 5 MSS frames and two MSS CCTs. N is total number of points, K is number used, R is vector error.

		AFFINE				Second order polynomial				collinearity equations 4 parameter				collinearity equations 7 parameter			
Image	N	K	X	Y	R	K	X	Y	R	K	X	Y	R	K	X	Y	R
220-22	53	53	62	58	85	53	51	49	71								
		9	70	56	90	9	59	60	84	9	124	199	234	9	60	48	77
		4	68	68	96	7	64	60	88	5	104	156	187	5	57	50	76
219-22	78	78	59	67	89	78	56	65	86								
		9	62	77	99	9	58	66	88	9	152	367	397	9	53	82	91
		4	64	85	107					5	105	204	220	5	51	71	87
218-22	50	50	60	58	83												
		9	71	73	102					9	124	136	188	9	64	48	80
		4	73	59	94					5	162	109	195	5	65	66	93
mean of 221-21 and 220-21	75	75	47	34	58	75	32	25	40	75	53	45	70	75	46	34	57
		9	55	37	66	9	35	32	47	9	59	41	72	9	54	39	67
		4	57	36	67					4	62	46	77	4	62	39	73
Digital images																	
217-24	157	157	50	53	73	157	46	47	66	157	121	108	162	157	56	60	82
		9	58	56	81	9	63	55	83	9	122	134	181	9	59	68	90
		4	53	59	79					4	113	126	169	4	56	63	85
212-20	36	30	42	53	68	30	39	46	61								
		4	45	58	73												

orientation.

Variations of the sensor's space co-ordinates (X_C Y_C Z_C) and rotation about Z (κ) along the flight path can be represented by polynomials of the form:

$$F\ (X_C, Y_C, Z_C, \kappa) = a_0 + a_1 y + a_2 y^2 + a_3 y^3 + \ .....$$

where y is the co-ordinate along the flight path. Four cases were tested. In case one (4 parameter adjustment) the constant term only was considered for each variable, in case two (7 parameter adjustment) the second terms were added in the case of X_C Y_C and Z_C, in case three (the 13 parameter adjustment) third and fourth terms were added for the co-ordinates and in case 4 (the 15 parameter adjustment) second and third terms were also added for κ. A summary of results is given in Table 1. The use of cases 3 and 4 showed no improvement over cases 1 and 2 and so no results are given. Root mean square errors are are computed from all available control points in every case.

Parametric correction

It is possible to compute and correct the lateral offset of the scan lines caused by the bend of the sub satellite track caused by earth rotation and map projection (Kratky, 1974).The distortion at a point is a function of the geographic co-ordinates of the point so that if the geographic co-ordinates of the scene's centre is known the correction to the point can be computed without any need for ground control points. Table II shows the root mean square error computed from residuals at check points after applying similarity transformations before and after applying the parametric corrections for digital rectification of two MSS scenes.

TABLE II: Root mean square errors in metres at ground scale derived from residuals after similarity transformation before and after parametric corrections.

		before parametric correction				after parametric correction		
Image	N	K	X	Y	R	X	Y	R
217-24	157	2	93	167	191	66	59	88
		4	116	123	169	50	59	83
212-20	36	2	228	94	247	80	55	97
		4	116	166	203	58	75	95
		30	163	109	195	66	65	93

Discussion on two dimensional methods

The following conclusions can be reached from the results in Tables I and II:

There is no significant advantage in using polynomial or collinearity methods rather than affine.

There is no great advantage in using more than four control points.

Enhanced images 221-21 and 220-2- give better results than images which were not enhanced.

Parametric adjustment using only two control points is a very economical method but data from other receiving stations may not respond in the same way.

Stereophotogrammetric methods

Working with scenes covering the United Kingdpn (north of 51° latitude) with an adequate overlap between adjacent orbits, stereo photogrammetry was employed to investigate the potential of MSS images for topographic mapping, especially with regard to the accuracy of height information and the possibilities of using analogue plotting instruments.

Two models were formed by analogue and analytical means. Both had relief of 900 m. The Wild A8 was used to test analogue methods, model co-ordinates were recorded with a precision of ±15m in plan and ±27 m in height. A modified relative orientation method was used to form a model from the stereocomparator data. If a point on the normal to the centre of a scene is taken as the nominal perspective centre for that scene and this has a co-ordinate vector $(X_{c01}, Y_{c01}, Z_{c01})^T$ then, because of the nature of scanning imagery the perspective centre relating to any point on the image, if given co-ordinates $X_{cj1}, Y_{cj1}, Z_{cj1}$, can be expressed as:

$$\underline{X}_{cj1} = \underline{X}_{c01} + \underline{F}(y_{j1}) \qquad (1)$$

where $\underline{F}(y_j)$ is a function representing the variation in position of the perspective centre from the position of the nominal perspective centre for a point j and can be given the form of a polynomial where y is the along track co-ordinate. Similarly a point on an adjacent orbit will have a corresponding perspective centre with co-ordinates:

$$\underline{X}_{cj2} = \underline{X}_{c02} + \underline{F}(y_{j2}) \qquad (2)$$

Subtracting the (2) from (1) we obtain the base components of an individual point as:

$$\underline{B}_j = \underline{B}_0 + \underline{F}(y_{j1}) - \underline{F}(y_{j2})$$

where B_j is a vector of base components relating to point j and B_0 is a vector of base components relating to the model with nominal perspective centre co-ordinates X_{c01} and X_{c02}.

In the tests which were carried out only the linear terms in y_{j1} and y_{j2} were used. The root mean square y parallax after relative orientation improved from ±116μm with a conventional relative orientation with 5 unknowns to ±37μm in one model and from ±83μm to ±22μm in the other. The formulae for relative orientation take into account the shifts to the perspective centre as scanning takes place but no changes in sensor orientation; to correct the model co-ordinates two different mathematical models were used; these were:

1. A three dimensional affine transformation with a total of 12 parameters.
2. Case 1. extended to second order polynomials with a total of 21 parameters.

Case 2 was extended to include up to 48 parameters but as there was no significant improvement the results are not given. A method was also used which allows the constant term in the polynomials to vary according to the position of each point in the image, but again no significant improve-was noted. A further method using intersection was developed. The elements for exterior orientation were determined using the modified collinearity equations described above, that is each scan line effectively has its own perspective centre. The model co-ordinates were then computed from the intersection of the rays passing through these perspective centres and the corresponding points of detail. The co-ordinate Z_j of a point j was then corrected using a ploynomial of the form:

$$Z'_j = \lambda Z_j + a_0 + a_1 x_j + a_2 y_j + a_3 x_j^2 + a_4 y_j^2 + a_5 x_j y_j$$

where $x_j y_j$ are the image co-ordinates of point j.

TABLE 3. Root mean square errors in metres at ground scale derived from residuals at check points after transformation of model co-ordinates to ground control.

		Analogue Model					Analytical Model				
Images	Transformation	N	K	X	Y	Z	N	K	X	Y	Z
219-22	Affine	60	60	64	82	123	49	49	74	94	89
	12 parameters		10	61	81	105		10	71	102	60
220-22								7	76	141	120
	Polynomials	60	60	63	73	101	49	49	55	65	82
	21 parameters		10	60	63	78		10	70	67	83
								7	72	68	181
221-21	Affine	56	56	139	258		50	50	188	266	
		163	163			162	88	88			161
220-21											
	Polynomials	56	56	44	43		50	50	44	45	
		163	163			124	88	88			131

TABLE 4. Root mean square errors in metres at ground scale after space intersection using elements of exterior orientation derived from midified collinearity equations and model deformation by polynomials with I terms.

Images	I	N	K	X	Y	Z
219-22	4	48	5	134	169	65
220-22	7	48	5	56	60	57
	13	48	7	64	57	57
221-21						
220-21	4	47	47	45	47	-
		79	79	-	-	104

N - number of points, and K - number of points used in adjustment.

The results shown in Tables III and IV indicate that stereo photogrammetric methods give results in plan which are very similar to those obtained with single images, for this purpose then there is no advantage in using three dimensional methods because of the additional computation required. In height, however, the results are most surprising, especially with the intersection method (Table 4). Welch and Lo (1977) show that the theoretical accuracy of heights from Landsat images is ±250 m with a base to height ratio of 0.11 but their practical results were worse than that. The images used at UCL were in band 6 and the base to height ratio was 0.11, using x10 magnification and using 7 control points the best results was ±57 m which compares with ±310 m from Welch and Lo in band 5 with 5 control points.

The enhanced images supplied by the UK NPOC did not give such good results as the images from Fucino and posssibly different processing methods give different results. It should also be noted that there was not much difference between the results obtained by analogue means on the Wild A8 and the corrected results obtained from analytical methods.

A heighting accuracy of ±60 m on Landsat images implies a precision of parallax observation of ±6μm which is possible on well defined points and this assumes that the corrections which are applied account for all orientation and scanner errors. Such accuracy would not of course be possible for contours and does not suggest that Landsat could be used for anything but very crude height determination. The nature of observational precision on very small scale images raises interesting questions and needs more thorough investigation.

MSS image rectification

A suitable mathematical model for rectification could be decided upon according to requirements after geometrical analysis. The simplest method of using the selected models is to superimpose a distorted grid onto the photograph. This product is suitable for use in the field or for transferring data onto existing maps. Figure 2 shows a MSS image with a superimposed grid. Second order polynomials computed from nine ground control points were used for the transformation and the grid was plotted on the graph plotter of the IBM 360 computer. A check on accuracy after superimposition showed that when co-ordinates of 20 points were obtained by reference to the grid the root mean square errors were ±61 m in Easting and ±58 m in Northings.

Digital rectification of MSS imagery produces a correct image on a square grid. Konecny (1979) has discussed possible methods and the indirect method described by him involves the specification of a point on the correct co-ordinate system and the determination of the corresponding image in the uncorrected data. An interpolation or resampling method is required to produce a new data set. Normally nearest neighbour, bilinear interpolation or cubic convolution methods are used. Nearest neighbour is the most ecomonical in terms of computer time but causes discontinuities in the image, cubic convolution is almost twice as expensive in computer time but bilinear interpolation gives a good compromise between expense and accuracy.

The Geometric accuracy of rectification was tested using a nearest neighbour resampling method and an affine transformation for image 217-24. Twelve control points were located on the computer produced five class map (Figure 3) printed on a graph plotter; root mean square errors were found to be ±52 m in Eastings and ±38 m in Northings.

Conclusions

The work at University College London using traditional photogrammetric instruments and a main frame computer show that useful products can be obtained from Landsat MSS images without special equipment. Geometrically corrected images can be produced on a graph plotter and simple classification enables the result to be used for monitoring change and for transfer of interpreted information onto accurate base maps. The superimposition of a grid onto a photograph enables positional reference to be made in the field.

Heights can be found to a surprisingly high accuracy which can be useful in unmapped areas of high relief. More work is necessary to improve this method and to show why the practical results exceed the predicted accuracy.

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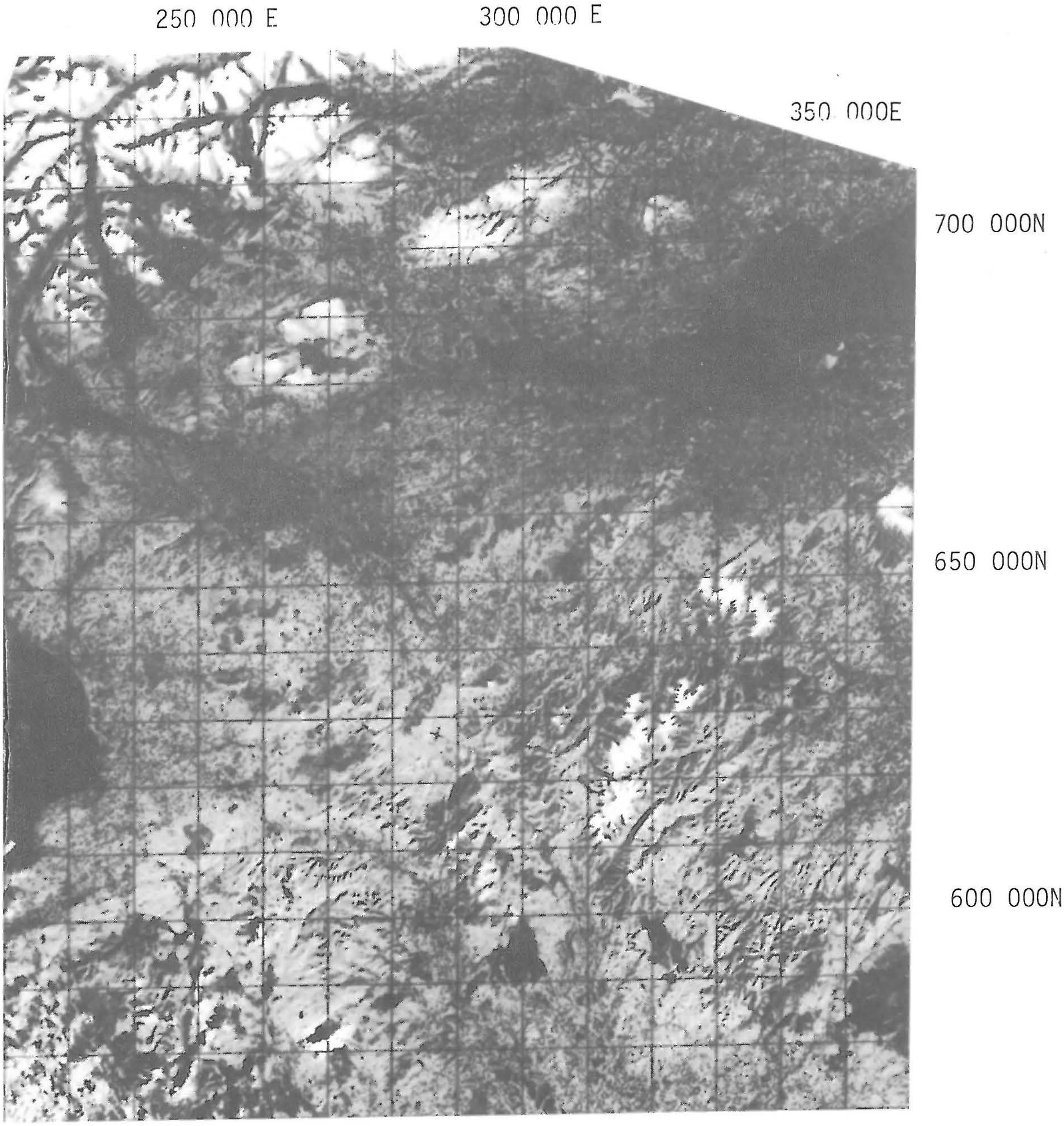

Figure 2. Grid superimposed on Landsat 2 band 6 image of the Glasgow and Edinburgh region. National Grid co-ordinates shown in metres.
Scale approximately 1:1 000 000.

Figure 3. Part of five class map produced from band 6 to check accuracy of digital rectification.