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A PROPOSED POLYNOMIAL FOR GEOMETRIC RECTIFICATION OF ORBITAL SAR IMAGERY

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ABSTRACT

Geometrical charateristics of orbiting SAR imagery was described and geometric distortions were analysed.
A proposed polynomial for geometric rectification of SAR images was developed, tested and compared with other mathematical modeles. A film of Seasat-SAR swath was used. About 100 ground control points were measured in both the SAR film and the 1:50,000 topographic maps. Transformation of image co-ordinates into ground co-ordinates was performed using the prposed polynomial and other mathematical models. The reuslts show that due to the stability of the Seasat's platform the minimum number of control points can be used for geometric rectification of SAR imagery. Rectified SAR imagery may be used for map revision of very small scale topographic maps and for land-use mapping. Also, it was appeared that the geometric acccurancy of SAR imagery is comparable with Landsat-MSS image accuracy.

INTRODUCTION

Seasat-1 was lounched in July 26, 1978 by NASA for sea and ocean monitoring applications with main objective to measure global ocean dynamics and physical characteristics and to determine key functions for an operational system. On November 21, 1987, NASA declared that the Satellite lost after a failure in the power sybsystem which occured on October 9, 1987.

Seaset-1 was operating at an altitude of about 800 km in a near-polar orbit, and has carried five different sensors, one of these was Synthetic - Aperture Radar (SAR).

The SAR sensor is a single-channel Synthetic-Aperture with nominal wavelength of 25 cm. It was designed to provide images of ocean waves, sea and fresh water, ice and snow cover and of land surfaces. Its aim was to demonstrate the environmental monitoring capability under day, night and all weather conditions.

SAR was working as one-side looking (SLR) covering a 100KM swath from 200 to 300 km on the north side of the satallite track. This paper summaries the SLR geometry and analyses geometric distortions and geometric accuracy tests in order to assess the possibility of using SAR imagery for very small-scale mapping.

SLR GEOMETRY

Ground co-ordinates of a target point 'P' are as shown in Fig.1. Image co-ordinates could be defined so that x-axis is in the direction of the spacecraft movement and y-axis is perpendicular and represents the timing of the receiving signals. In case of slant-range reading, y co-orindate of an image-point "p" is proporational to the distance between the object-point "P" and the electrical centre of the Radar's antenna. Ground-range representation reduces slant-range into ground-range distance which is proportional to the orthogonal projection of the range vector. The X co-ordinates of an image point 'P' is a function of the time at which the object point "P" was imaged.

Geometric distortions of the SLR imagery caused mainly by; Earth curvature and rotation, relief and change in the platform's attitude. Other sources such as squint, interior orientation parameters and processing errors may cause additional geometric distortion.

ANALYSIS OF GEMETRIC DISTORTIONS

Figures 2 and 3 show the effect of Earth curvature and relief displacement on ground-range where the combined distortion resulted from these two sources may be written as:-

$$Y = Y \{1 + H/(R+H)\} + Y\{1 + h/Y^2 (2H-h)\}^{1/2} - 2Y \qquad (1)$$

For high altitude orbiting satallites such as Seaset and landsat, each rotation during platform movement will cause the real-flight path to be skewed by an Earth rotation angle (He); its value will depend upon the geographic position and the angular velocity of the orbiting platform. For a small section of SAR swath, the Earth rotation angle (He) could be assumed constant, so that its effect will be a displacement in the range-direction of the real-track which may be expressed as:

$$dY = He \,.\, X \qquad (2)$$

Where X is the co-ordinate in azimuth direction. Change in the platform attitude along the flight path will cause image distortion. Image displacement due to changes (errors) in the platform's exterior orientation elements (dX, dX, dZ, dw, dØ, dk) have been analysed by Leberl (1972) and can be expressed as:-

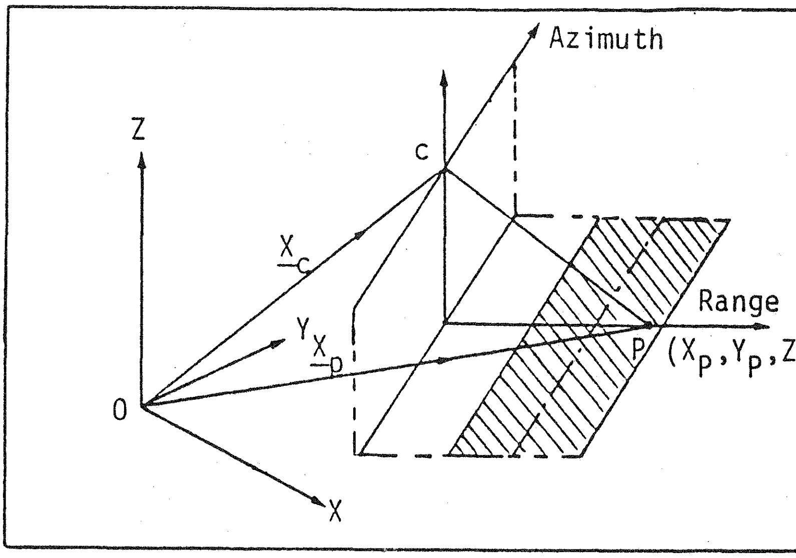

Fig. (1) SLAR co-ordinates system

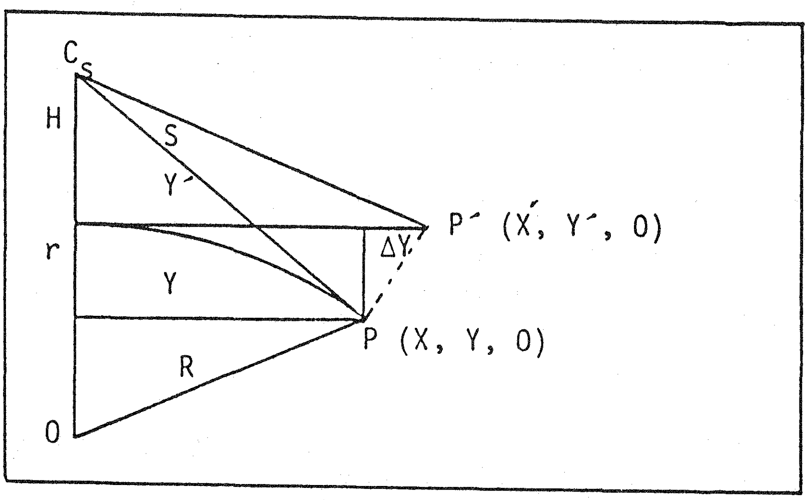

Fig. (2) Earth curvature - R = Earth radius; S = slant range to point 'P'; H = satellite altitude

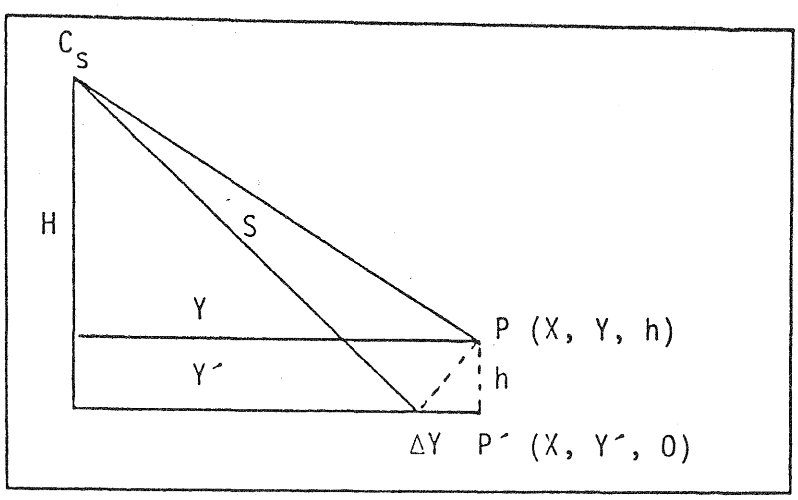

Fig. (3) Relief displacement

$$dx = a_0 Y + dk.Y - d\phi.H \quad (3)$$

and

$$dy = dZ\,H/S - dY\,Y/S \quad (4)$$

where:-

X, Y are ground co-ordinates of any target point,
S is the slant-range,
H is the platform's altitude, and
a_0 is a constant represents changes (errors) in the platform speed.

DERIVATION OF SAR RECTIFICATION POLYNOMIALS

The collected effects of erroneous exterior elements on SAR imagery, Equations 3 and 4, together with the Earth curvature and rotation and relief, Equations 1 and 2, amy be expressed as:-

$$dx = a_0 Y + dk.Y - d0.H \quad \text{and}$$
$$dy = dZ.H/S - dY.Y/S - 2Y + Y\{1 + H/(H+R)\}^{1/2} + Y\{1+h/Y^2(2H-h)\}^{1/2} \quad (5)$$

Since the changes in the exterior orientation elements are not measured, they could be expressed as a function of the azimuth and applying this to Equations (5) with some approximations, one can obtains:-

$$dx = a_0 + a_1X + a_2Y + a_3X^2 + a_4XY + a_5X^2Y \quad \text{and} \quad (6)$$
$$dy = b_0 + b_1X + b_2Y + b_3/Y + b_4X/Y + b_5X^2/Y$$

where:-

dx, dy represent distortion in image co-ordinated and X,Y are ground co-ordinated of any target point.

DATA AND OBSERVATION

A film of SAR swath number 762 was used in this experiment. The full swath is divided into four subswathes 70 mm each with total swath width of about 100 km. Each subswath covers about 49 km width ground strip with about 33% side overlap with the adjacent subswath. A section of that swath which covers the area of Eat Anglia in the UK was chosen to carry out this investigation. No geometric correction have been applied during the production of this SAR film

About 100 ground control points were identified in both the SAR image and the 1:50,000 topographic maps. Coast lines, lakes, big canals and boundaries of woodlands were easy to recognize

Image co-ordinates were measured on a stereocomparator with standard deviation of ± 20 Um image scale. Ground co-ordinates were derived from the 1;50,000 topographic maps with an accuracy of about ±15 M.

GEOMETRIC ACCURACY TEST

Geometric accuracy of SAR images was carried out by fitting image co-ordinates to ground co-ordinates by means of different mathematical models. Similarity and affine transormations in addition to general and derived (proposed) polynomials were used.

Geometric transformation was applied first for each zone individually. A block was formed by joining the four subswathes (zones) together by affine transformation using 7-Common points between each to adjacent zones. Image co-ordinates in the formed block, then, fitted into ground co-ordinates in the same way as in the first experiment.

Least squares method was used to determine transformation parameters and then residuals and root mean square errors (RMSE) at the check points were calculated and residual vectors were plotted.

THE RESULTS

Tables 1 and 2 show the obtained results of geometric accuracy tests as described in the previous paragraph. In these tables, 'N' is the total number of control points and 'K' is the number of points used for transformation.

Results indicated that geometric distortion in SAR images could be corrected successfully by polynomials. Ground control up to 10 points may be enough for SAR rectification.

Resulted average RMS error vector of about ±50 m after applying 7-elements polynomial is quite reasonable, bearing in mind accuracy of measured image and map co-odinates.

The proposed polynomial gave results comparable to those obtained by the 7-elements polynomial however this polynomial requires less ground control points. The obtained accuracy is comparable to other SAR geometric aaccuracy tests carried out by other investigators.

CONCLUSIONS

The main conclusion is that increasing the number of ground control points has no significant advantage, once the right mathematical model have beeen applied.

TABLE (1)

ROOT MEAN SQUARE ERRORS IN METRES COMPUTED FROM RESIDUALS AT CHECK POINTS AFTER FITTING IMAGE CO-ORDINATES IN EACH ZONE TO MAP CO-ORDINATES

Zone	N	K	Similarity		Affine		...General Polynomials				The Specific Polynomials	
							6-Elements		7-Elements			
			X	Y	X	Y	X	Y	X	Y	X	Y
I	30	4	297	954	55	110						
		7	362	934	53	120	41	69	37	48	47	52
		10	363	900	52	115	34	76	38	47	45	50
		30	214	947	50	112	37	46	36	40	39	47
II	24	4	137	360	84	135						
		7	131	372	73	120	34	61	36	44	41	57
		10	136	339	71	115	42	44	32	37	32	51
		24	127	313	71	103	32	51	37	33	38	49
III	32	4	237	389	56	79						
		7	272	381	67	92	46	55	37	49	35	44
		10	292	407	64	93	44	53	36	48	41	41
		32	222	396	57	80	34	45	34	41	33	44
IV	13	4	143	413	47	56						
		7	136	417	43	55	42	67	33	55	37	52
		10	310	308	43	57	45	45	32	44	25	52
		13	165	403	43	57	46	46	25	48	25	51

TABLE (2)

ROOT MEAN SQUARE ERRORS IN METRES DERIVED FROM RESIDUALS AT CHECK POINTS AFTER FITTING IMAGE CO-ORDINATES OF THE FORMED BLOCK TO MAP CO-ORDINATES

N	K	Similarity		Affine		General Polynomials								The Specific Polynomials	
						6-Terms		7-Terms		9-Terms		11-Terms			
		X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
	4	478	1150	500	1120										
	8	502	1085	377	637	70	152	59	61					62	61
78	12	515	1055	371	780	66	126	51	55	62	74	70	126	54	54
	78	471	931	357	806	52	98	46	52	44	52	43	49	51	51

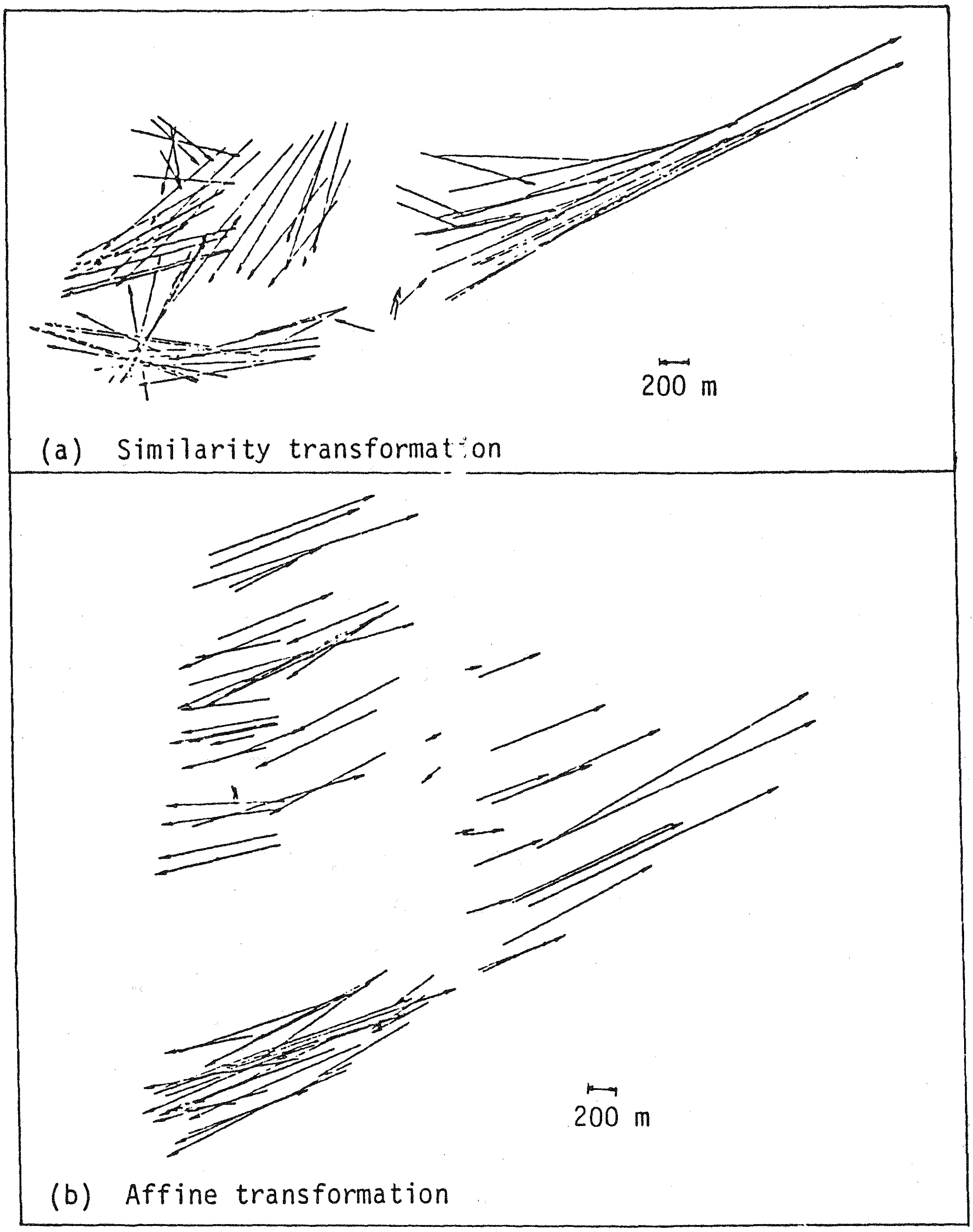

Fig. (4) Residual distortion vectors in the SAR formed block after similarity and affine transformations.

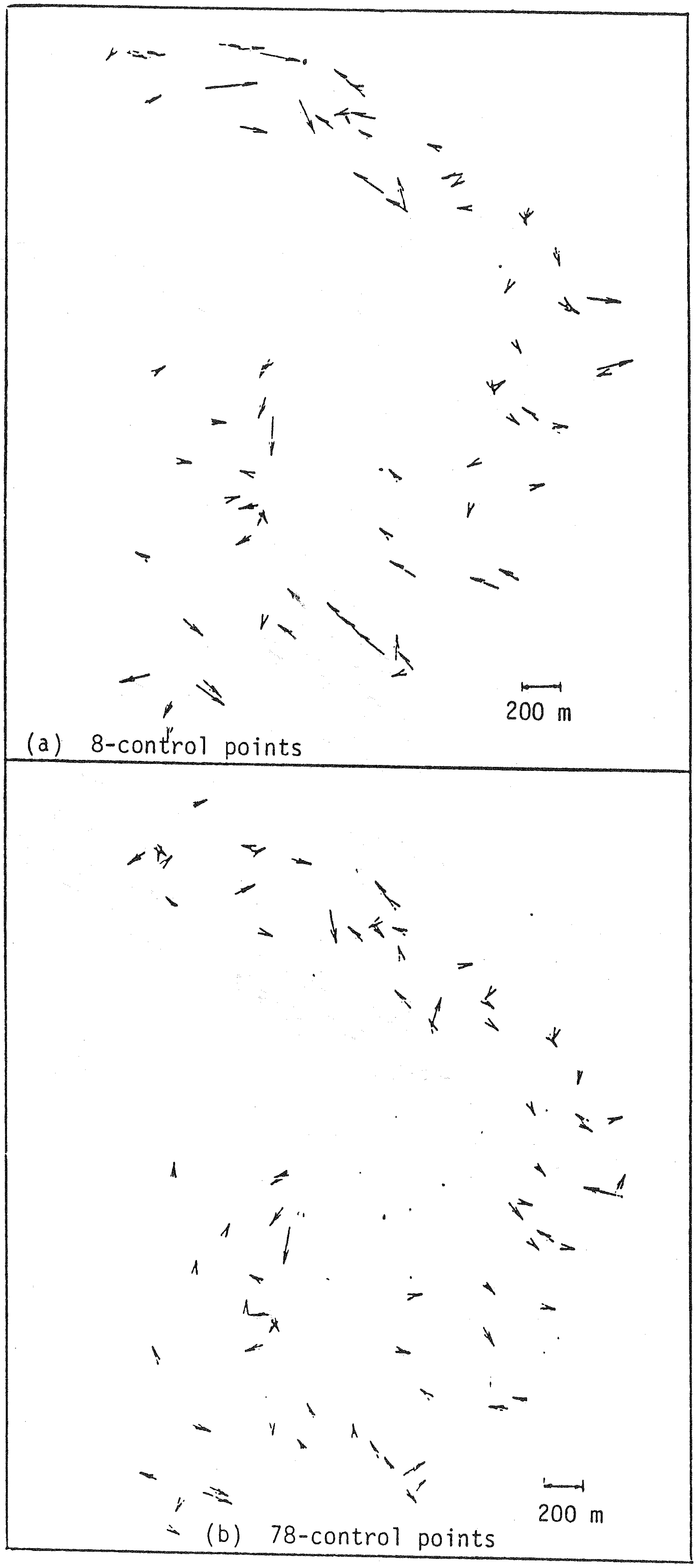

Fig. (5) Residual errors at the formed SAR block after the proposed (theoretical) polynomials.

Due to the day and night and all weather operation capabilities of Imaging Radar Systems, SAR imageries offer a good solution for mapping areas in the third world with poor map coverage and hwere a weather problems exist.

Finally, it can be concluded, regarding obtained geometric accuracy of Seasat SAR imagery, that these accuracies meet the geometric accuracy requirements of planimetric mapping with scales of 1,150,000 and smaller.

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