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MEASURING GROUND CONTROL POINTS FOR SATELLITE IMAGE RECTIFICATION

H. Malmström, Stockholm

1. Introduction

This paper presents results from a research project carried out at the Royal Institute of Technology, department for Photogrammetry. The project was partly sponsored by the Swedish Board for Space Activities.

Geometric rectification of satellite images to a reference coordinate system facilitates the comparison of the satellite images with other types of geographic information. The bases for the rectification are a mathematical model, describing the relationship between the recorded image coordinate system (line, pixel) and the reference coordinate system (X,Y,Z), and Ground Control Points with known coordinates in both coordinate systems.

The demands for geometric quality on the rectified image depends on the use of the image. Radiometric interpretation of a single satellite image requires very limited geometric quality compared with mosaicing several satellite images together.

In the field of image processing the interest of subpixel positioning has been limited. The interest has been focused on image content and the basic unit of position has been one pixel.

In mapping the position of an object is as important as the content of the object and this fact has increased the interest and demands for subpixel positioning, as mapping is going into digital information handling and image processing.

Comparison of geographic information from different sources (maps, aerial photos, satellite images, etc.) and from different periods (seasons, years) requires high geometric precision of the images. Mosaicing of several images and parallax measurement of overlapping images for generation of Digital Elevation Models are other areas which require subpixel positioning.

Performance of systems for satellite image recording are increasing, the radiometric and geometric resolution increases and the variations of platform attitude decreases. With this development the users will demand better quality on the final rectified product. Mathematical models for geometric rectification are continuously refined in order to fulfill these requirements. These circumstances will also increase the demands for better quality of the Ground Control Points.

This paper is concentrated on Ground Control Point measuring in satellite images. A method with digitized aerial photographs is presented together with results from an evaluation test. Identification of control point objects and methods for measuring ground coordinates are also discussed.

2. Methods for Obtaining Ground Control Points

2.1 Characteristics of Ground Control Points

The main criteria of a Ground Control Point is first that it shall be easily and uniquely defined and second that it shall be located with high precision. These demands shall be fulfilled both for the unrectified image and for the ground. The demands are somewhat contradictory, a small distinct precise object can be located with high precision but it is not easily identified (hard to find, possibility of identification error). A big object is easier to identify, but what defines its position (average of edge coordinates or centre of gravity)?

High contrast with the background is important because that defines the control point in a digital image. A common tool for pointing at control points in digital images is the cursor (dot or haircross with the size of 1 pixel or of 3 x 3 pixels). In order to give the operator in front of the screen an easy and quick job the control point object shall be symmetrical with a size of not more than a couple of pixel.

The choice of method for measurement of the control points on the ground depends on the demands for economy, on the demands for geometric accuracy and on the availability of existing ground measurements (old maps, photos, geodetic nets etc.).

An important fact for achieving correct control points with accurate coordinates is that their definition in the satellite image and on the ground are identical. There are several reasons for discrepancies between image and ground. Temporary (varying water level changes the size and form of islands) or permanent (reconstructions of road crosses) changes of the physical control point object "moves" the object.
Different lookangles for different sensor systems causes identification difficulties and geometric distortions. The wavelength of the reflected light varys with sunangle, season of the year etc. These variations in wavelengths together with differences in spectral sensitivity of different sensors will cause different appearance of a control point object.

The desirable type of control point object is not permanent and varys with the performance of the sensor system and with the demands for geometric accuracy in the final rectified image. Common ground control objects for Landsat MSS are small islands and road intersections. These objects are local intensity min/max with the form of a point or a small surface.

2.2 Measuring Ground Control Points in digital images

When subpixel positioning is of no interest, control points can be measured on a screen, filmcopy or a lineprinter output by identifying the line and pixel of the control point object. Manual interpolation between integer coordinates increases the measuring precision.

The screen can sometimes limit the possibility to identify and point at a control point. If the resolution of the screen is low or the cursor movement is rough, a zoomed subimage (duplicated pixel values) will increase the measuring precision. Finally the zoom can be done with cubic convolution which will eliminate the "staircase" effect of the duplicate zoom.

2.3 Measuring Ground Control Points on the ground

Ground Control Points can be measured on the ground with several equipments/methods:

- maps
- orthophotography
- photogrammetry
- terrestrial geodesy
- satellite geodesy

Maps and orthophotography are of interest if existing products over the area are available. Control point identification is easiest with orthophotography and photogrammetry because they consist themselves of images and can therefore be compared directly with the satellite image. Control points measured with geodesy must in most cases be supplemented by a point description or a photo in order to be visible for identification in the satellite image.

The accuracy of control points from existing small scale maps have so far been sufficient for most applications. With better satellite sensor system performance the number of control points for one image can be reduced without loss of accuracy. Increased internal stability of satellite images opens the possibility of block triangulation of several images. This development favours the satellite geodesy as high accuracy over great distances is required for a few number of points.

3. Digitized Aerial Photographs as Ground Control Points

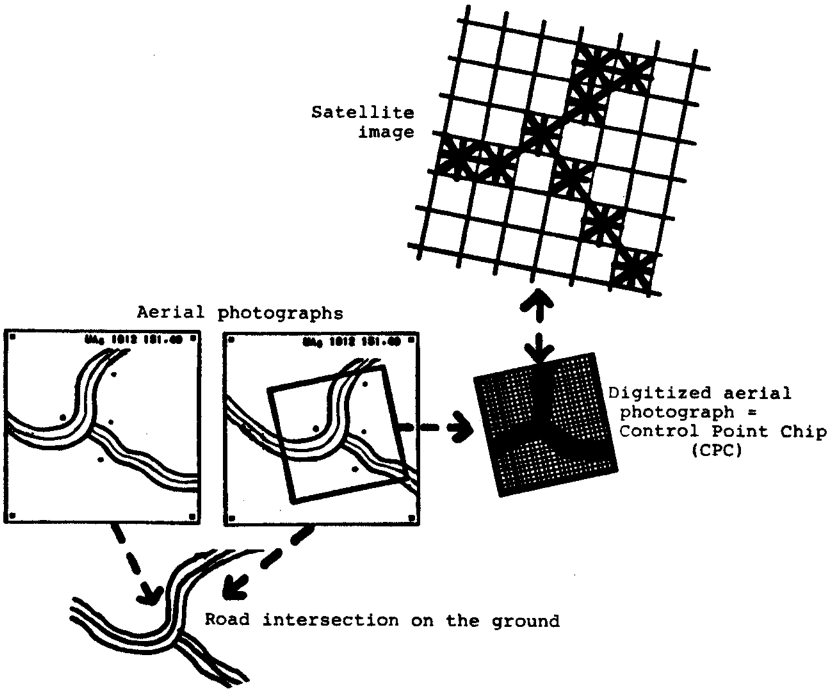
3.1 Basic idea

A digitized aerial photograph is introduced as an intermediate step between the satellite image and the ground in this method for Ground Cotnrol Point acquisition. The aim with such a solution is:

- to get photogrammetric accuracy in ground coordinates
- to eliminate the manual time-consuming precise positioning of the cursor in the satellite image and use matching technique for coordinate measurement in the satellite image
- to get better precision in the measurement of coordinates in the satellite image
- to increase the number of possible control point objects. When matching technique is used, bigger and irregular objects can be used as control points.

3.2 Methodology for measurement of one Ground Control Point

Control Point objects are selected by studying aerial photographs and the satellite image. The area around every control point object in the aerial photograph is digitized with high resolution in a scanner. Such a digitized subarea of an aerial photograph is named a Control Point Chip (=CPC).



3.2.1 Determination of ground coordinates for a Control Point Chip

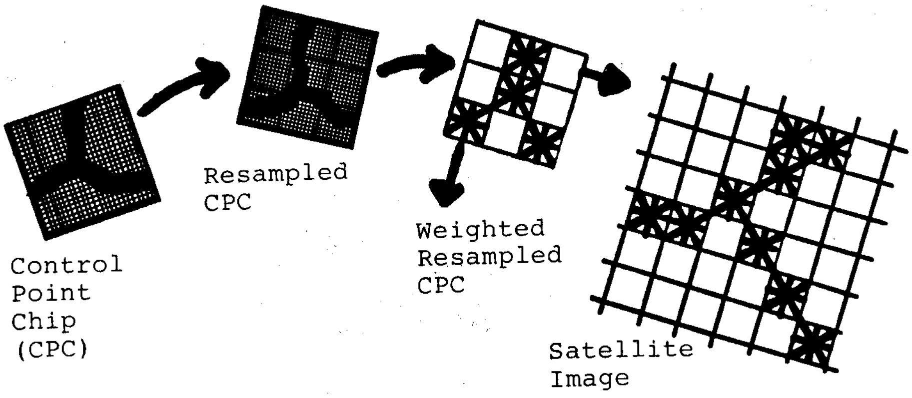
The analogue photograph and its stereopartner is measured in a stereoplotter, where ground coordinates (X,Y,Z) in the reference coordinate system can be read.
The Control Point Chip is presented on a screen where coordinates (line, pixel) of the cursor can be read.

Identifiable details on or just outside the control point object are mearsured in the stereo model and the same homologous details are also mearsured in the CPC on the screen with pixel-pointing (Pixelpointing = positioning of cursor to closest integer line/pixel coordinate).
The just measured coordinates are used to calculate coefficients for an affine transformation from the CPC (line,pixel) to the reference coordinate system (X,Y).

3.2.2 Determination of satellite image coordinates for a Control Point Chip

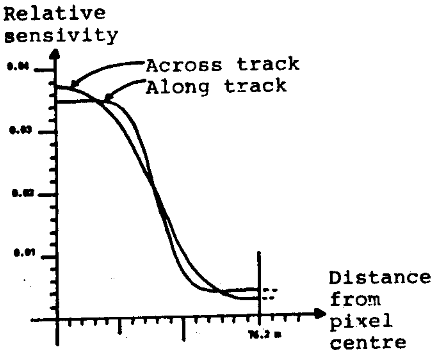
The matching algorithms used to calculate the position of the CPC in the satellite image only content parameters for translation. Therefore differences in rotation and scale between the digital images must be reduced to negliable values before matching (negliable inside the size of a control point object). Outgoing from the orbit data, coefficients for a affine transformation from the recorded satellite image (line, pixel) to the reference coordinate system (X,Y) are calculated. These coefficients are put together with the affine coefficients from the CPC to the reference coordinate system which finally yields coefficients for an affine transformation from the CPC to the recorded satellite image.

The CPC is resampled to the coordinate system of recorded satellite image. In this resampling the pixelsize of the resampled CPC is choosen to 1/10 of the pixelsize of the satellite image. This high resolution is later used in the matching process.

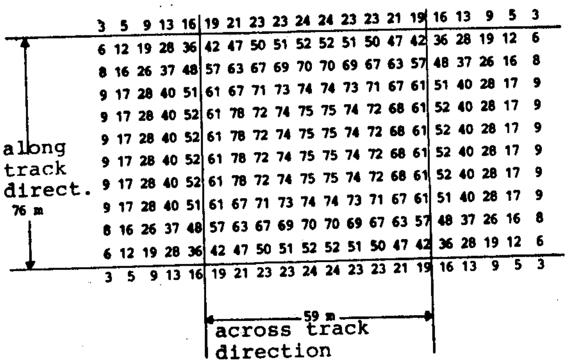


Matching part one

In the matching calculations the pixel size of the resampled CPC are first increased (10 times in each direction) by weighting the pixels together. The weights are obtained from the Point Spread Function (PSF) of the satellite sensor (Friedmann, 1980, Larsson et al, 1981 and Malmström, 1984).



Point Spread Function of the satellite sensor in along track direction and across track direction.



3	5	9	13	16	19	21	23	23	24	24	23	23	21	19	16	13	9	5	3
6	12	19	28	36	42	47	50	51	52	52	51	50	47	42	36	28	19	12	6
8	16	26	37	48	57	63	67	69	70	70	69	67	63	57	48	37	26	16	8
9	17	28	40	51	61	67	71	73	74	74	73	71	67	61	51	40	28	17	9
9	17	28	40	52	61	78	72	74	75	75	74	72	68	61	52	40	28	17	9
9	17	28	40	52	61	78	72	74	75	75	74	72	68	61	52	40	28	17	9
9	17	28	40	52	61	78	72	74	75	75	74	72	68	61	52	40	28	17	9
9	17	28	40	52	61	78	72	74	75	75	74	72	68	61	52	40	28	17	9
9	17	28	40	51	61	67	71	73	74	74	73	71	67	61	51	40	28	17	9
8	16	26	37	48	57	63	67	69	70	70	69	67	63	57	48	37	26	16	8
6	12	19	28	36	42	47	50	51	52	52	51	50	47	42	36	28	19	12	6
3	5	9	13	16	19	21	23	23	24	24	23	23	21	19	16	13	9	5	3

Weight matrix for weighting CPC-pixels together to one satellite pixel. The weights are the number above devided by 10 000. The nominal size of one satellite pixel is marked in the figure.

The position of best similarity between the weighted resampled CPC and a corresponding subarea of the satellite image is calculated with matching technique. Two different matching algorithms have been tested: Sequential Similarity Detection Algorithm (Kaneko, 1976) and Cross Correlation.

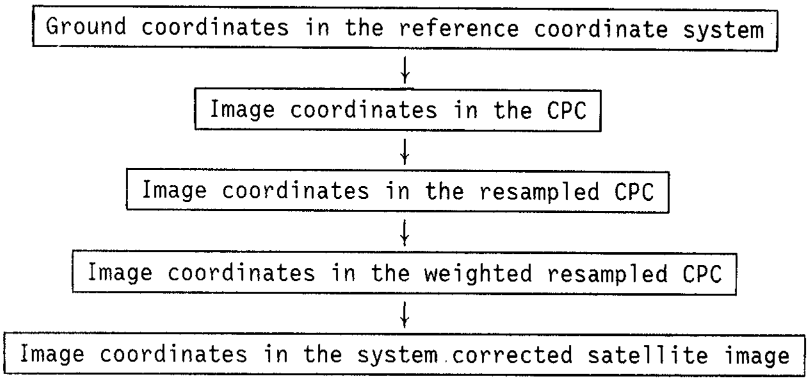
Matching part two

In the second matching part a third matching algorithm has been tested, Least Square Matching (Förstner, 1982). Based on the found position of best match (from part one) in the satellite image the matching calculation is repeated with the same subarea of the satellite image. Between every match calculation, the weighting of the resampled CPC is repeated with different starting position for the weighting (the minimum translation of the weighting starting position is 0.1 satellite pixel). This means that the resulting shifts from the match calculation are used to locate the starting position of a new weighting calculation.

This second matching part is continued until a given criteria is fulfilled (translation < 0.05 satellite pixel or maximum 5 iterations).

3.2.3 Calculation of final coordinates for one Ground Control Point

The results from all the described calculations in this chapter are summarized in one final calculation. Coordinates for a representative point on the control point object on the ground are transformed with the calculated coefficients:



This yields our final goal:
Known coordinates in the satellite image and
known coordinates on the ground
for one Ground Control Point.

4. Practical Test

4.1 Purpose

The purpose of the test was:

- to find out how the described methods works in practice
- to compare different similarity measure
- to find out if the described method yields better precision in control point measuring then pixelpointing and maps

4.2 Test material

Satellite image:	Landsat 3 MSS, system corrected band: 5 and 7, scene: 208/18, date: 79-06-11, pixel size: 57 m x 79 m 8 bit/pixel (pixel intensity: 0 - 255)
Aerial photographs:	6 black and white photos, flight heigt: 4600 m, scale: 1:30000, date: 77-07-09, hour: 11.00 a.m.
Size of test area:	North/South: 5.5 km East/West: 7.0 km
Control Point Object:	Gravel (road intersections or yards) with background of vegetation
No. of control points:	17 (15 in band 5 and 2 in band 7)
Size of the Control Point Chips:	4 x 4 and 6 x 6 satellite pixels

4.3 Calculations for each Control Point

The satellite image was presented on an EBBA-system (an image processing system from the Swedish Space Corporation) and control point objects were selected by means of the satellite image on the screen and the aerial photographs. Selected objects were mostly gravel yards or road intersections with an object size of 1 x 1 to 3 x 3 satellite pixels. The intensity of most objects was 100 - 130 with a background intensity of 30 - 40.

Each control point object in the aerial photographs was digitized in a scanner and the result (= the Control Point Chip, CPC) was stored on magnetic tape. Two control point objects were eliminated at this stage because of low contrast with the background.

Each CPC was then measured in order to position it in the reference coordinate system on the ground (six points for every control point object). A WILD A8 was used for measurement of ground coordinates with absolute oriented stereo models. The absolute orientation of the stereomodels resulted in a standard error (X, Y, Z) of 0.6 - 1.3 m. Image coordinates in the CPC was measured by means of the cursor on the EBBA-screen.

The calculations of affine coefficients from each CPC coordinate system to the reference coordinate system on the ground yielded a standard error of 0.4 - 1.4 m. Each CPC was then resampled to the coordinate system of the system corrected satellite image with an affine transformation and bilinear interpolation.
One control point was eliminated after the resampling because it was only 2 satellite pixels long in one direction.

In the matching of weighted resampled CPC in the satellite image the cross correlation coefficient was 0.63 - 1.00 for the thirteen control points. One control point was eliminated because it had a gross error in the starting coordinates.

The calculated shift in the least square matching had a standard error in each direction of up to 0.27 satellite pixel. The mean standard error in each direction was approximately 0.1 satellite pixel (= 6-8 m on the ground).

The maximum difference (for one control point) between cross correlation and least square matching in calculated position was 0.2 satellite pixels with a mean of 0.07 satellite pixel.

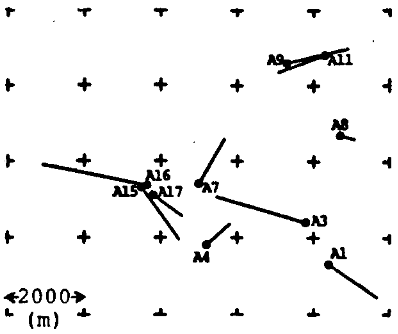
4.4 Final evaluation of the test

Depending on the method for control point measuring the result from the individual calculation was divided into the following groups:

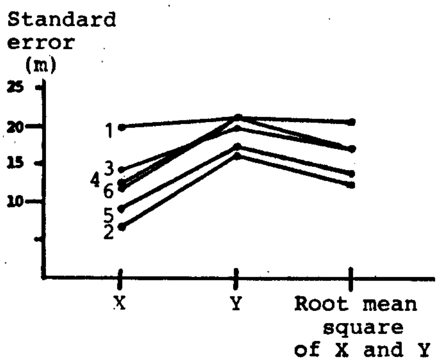
Group Number	Method	Number of points
1	Pixelpointing with manual interpolation	10
2	Least square matching (convergence criteria = 0.05 satellite pixel)	7
3	Least square matching (convergence criteria = 0.10 satellite pixel)	12
4	Cross correlation	13
5	Cross correlation (correlation coefficient > 0.90)	10
6	Sequential Similarity Detection	13

Affine coefficients from the system corrected satellite coordinate system to the reference coordinate system were calculated for each group with the following result:

Group Number	Standard Error on the ground (m)		
	X (North)	Y (East)	Root mean square of X and Y
1	20.0	21.1	20.6
2	6.7	16.2	12.4
3	14.3	19.9	17.3
4	12.5	21.1	17.3
5	9.0	17.3	13.8
6	11.9	21.0	17.0



Residuals after final calculation of affine coefficients for group 5.
10 m residual: o—



Standard error in the reference coordinate system (m) after final rectification. Group 1-6

The result of the experiment shows that:

- control points measuring with matching techniques yields better precision then measuring with pixelpointing
- the groups measured with matching technique show a better result in the X-direction then in the Y-direction.

5. Discussion

The method can be more effectively designed for practical work. An analytical plotter equipped with a chip-digitizer would reduce transportations of images, staff and results between different instruments and computers.

The performance of the method can be increased by measuring height information of the control point object. With a "local" Digital Elevation Model around every control point object it will be possible to resample the Control Point Chip to non-vertical lookangle. This characteristic is necessary for sidelooking satellites (e. g. SPOT).

The most time-consuming part in the test was to find the control points in the satellite image. The main reason for this was that the scale of the satellite image was not equal in line- and pixel-direction. The control point finding should be done in a re-scaled satellite image with equal scale in line- and pixel-direction.

The Sequential Similarity Detection Algorithm is a fast matching technique, but it is not well suited for the method as the computation time is not critical. A disadvantage is the lack of quality measure (of the found position) for gross error detection.

The difference in precision of the Cross Correlation and of the Least Squares Matching is very little. The Least Squares Matching demands good starting coordinates and is therefore used only in the second part of the matching.

The probable reason for the lower precision in the Y-direction is remaining errors in the satellite image after the system correction. The across-track direction nearly coincidence with the Y-direction where e. g. non-linearities in the scan velocity causes remaining distortions.

6. Conclusions

Method in practice

The method leads to a lot of work for control point acquisition. These high costs for control point acquisition are only motivated if the demands for quality of the rectified satellite images are high. For the type of satellite image used in the test the remaining errors from the system correction are greater than the precision of the control point measuring. For Landsat MSS it is not motivated to use the method for control point acquisition.

Similarity measures

The cross correlation is best for the first part of matching where the approximate coordinates are rough. The approximative coordinates are close to the final solution in the second part of matching and in this part the least square matching is favourable, as it presents the standard error of the calculated position.

Precision of the method

The errors in the along track direction are divided by two with the presented method compared with pixelpointing and maps. Further analyses are not possible because of remaining errors in the system corrected satellite image. The test shows that it is possible to measure control points in satellite images with a precision of 10-20% of the pixel size.

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Abstract

Geometric rectification of satellite images to a reference coordinate system (e.g. a map coordinate system) demands control points with known coordinates in both coordinate systems. This paper describes methods for control point measuring in the image and on the ground. A method with digitized aerial photographs for high precision control point measuring is described and tested. In the method ground coordinates are measured with photogrammetry and the satellite image coordinates are measured with digital matching technique.
The method reduces the standard error in the satellite track direction from 21 m to 6 - 14 m compared with manual pixel measuring and ground coordinates from a map. In the across track direction no improvement was found, probably caused by remaining distortions in the satellite image. The method leads to a lot of work and is only motivated if the accuracy requirements are high.

MESSUNG VON PASSPUNKTEN ZUR ENTZERRUNG VON SATELLITENBILDERN

Zusammenfassung

Die geometrische Entzerrung von Satellitenbildern auf ein Bezugskoordinatensystem (z.B. ein Landkartenkoordinatensystem) erfordert Paßpunkte mit bekannten Koordinaten in beiden Koordinatensystemen. In diesem Bericht werden Methoden für die Paßpunktmessung im Bild und im Gelände beschrieben. Eine Methode mit digitalen Luftbildern für die hochgenaue Paßpunktbestimmung wird beschrieben und erprobt.

In dieser Methode werden die Geländekoordinaten mittels Photogrammetrie und die Satellitenbildkoordinaten mittels digitalen Zuordnungsverfahrens gemessen.

Diese Methode reduziert die Standardabweichung in Richtung der Satellitenflugbahn von 21 m auf 6 - 14 m im Vergleich zur manuellen Pixelmessung mit Geländekoordinaten aus einer Landkarte. Quer zur Flugrichtung ergab sich keine Verbesserung, was wahrscheinlich auf verbleibende Verzerrungen im Satellitenbild zurückzuführen ist.

Dieses Verfahren ist sehr arbeitsintensiv und seine Anwendung nur dann begründet, wenn die Genauigkeitsanforderungen hoch sind.

Tekn Lic Håkan Malmström
Swedish Space Corporation
Albyg. 107,
171 54 Solna/Sweden.