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# PLANIMETRIC TRANSFORMATION OF SYNTHETIC APERTURE RADAR IMAGERY

Presented Paper by

Eugene E. Derenyi
Laszlo Szabo

Department of Surveying Engineering
University of New Brunswick
Fredericton, N.B., Canada

## ABSTRACT

The geometric characteristics of imagery recorded by the synthetic aperture radar (SAR) designed at the Environmental Research Institute, Michigan (ERIM) was ascertained with the help of dense network of control points. It was observed that distortions in range and azimuth direction were virtually uncorrelated. Based on this finding, eight and ten parameter transformations, from image to ground coordinate system, were developed for SAR data reduced from slant-to-ground range, and nine and eleven parameter transformations were set up for uncorrected data. The transformation formulae were tested on three strips of SAR imagery and the results compared to those obtained by similarity, affine and projective transformations and by two polynomial functions used previously for the processing of data recorded by other types of radar.

## INTRODUCTION

Continuing improvements in the spatial resolution of imaging radar systems coupled with a unique all-weather capability enhance the cartographic potential of radar imagery. Possible applications, in this connection, include the locating of targets in surveillance activities, displaying interpreted information in a spatial context and facilitating mapping and/or revision of maps in remote areas and in regions where unfavourable weather conditions persist. Although, it is possible to determine elevation from side-lapping strips, at the present time radar images are primarily regarded as a source of planimetric data.

Mapping in photogrammetric terms means the transformation of image coordinates to a ground coordinate system. To perform this task, one must formulate a mathematical model which not only performs the transformation, but also compensates for the numerous inherent systematic errors of the image. Leberl [1972] and others have studied in depth the geometric characteristics of side-looking radar and suggested various parametric and non-parametric methods for the transformation. For practical applications, however, it is most important to find an optimized solution to the problem at hand; that is to arrive at a method which provides an acceptable solution in the simplest possible way. Hence, an investigation is being conducted at the University of New Brunswick to develop such a method for the planimetric transformation of airborne synthetic aperture radar (SAR) imagery. The results obtained thus far are discussed in this paper.

## METHOD OF APPROACH

Acquiring radar imagery by a synthetic aperture system requires a rather complex integrated array of onboard navigational and control instruments. Testing the performance of each individual component and then propagating the errors to ascertain the geometric characteristics of the image is a rather complex operation. In addition, there are a handful of SAR system configurations in operation at present and none of them are identical. Therefore, it is more feasible to examine the final product, determine experimentally its geometric characteristics and then devise a suitable mathematical model for the transformation. Hence, this is the method of approach adopted for this project.

The imagery investigated was acquired with a dual-frequency, dual-polarization SAR, designed at the Environmental Research Institute of Michigan (ERIM) and installed in a Convair-580 aircraft of the Canada Centre of Remote Sensing. Hence, the configuration was referred to as SAR-580. The two frequencies of operations were the X and the L-band. The sensor was operating in a shallow angle mode, with a depression angle of 24.4° at the centre of the beam. At a flying altitude of 6 km above ground, this mode provided a ground range offset of 10 km and a swath width of 6 km. The imagery was recorded as a slant-range display at an approximate scale of 1:135000. Three strips of X-band recording in HH polarization were tested thus far. Each strip was about 55 km long.

Image coordinates were measured in a Wild STK1 comparator. The coordinate system was defined so that the x-axis was pointing in the azimuth (flight) direction. Ground control values were established by analytical aerotriangulation and block adjustment of 1:50000 scale photography and from 1:20000 scale orthophoto maps.

First the measured image coordinates were pre-processed, i.e. corrected for the effect of earth curvature and reduced to ground range using the average terrain elevation. No ground control points were employed at this stage. Next the pre-processed image coordinates were transformed to the ground coordinate system by an affine transformation using all available ground coordinates as control. The residuals at the control points were then plotted as a function of the location of the points on the image.

Through a detailed examination of these plots Szabo [1980] has found that the errors in range and azimuth direction are virtually uncorrelated. In particular, it was observed that

- there is no apparent functional relationship between the x-component of the residuals and the y coordinates;

- there is no apparent functional relationship between tye y-components of the residuals and the y coordinates;

- the x-component of the residuals is a function of the x coordinates;

- the y-component of the residuals is also a function of the x coordinates; and

- the change of the x-component as a function of the x coordinate tends to occur at a faster rate than that of the y-component.

Based on these - rather subjective - conclusions, corrections can be applied to the image coordinates, whereby

$$x' = x + \Delta x(x) \quad \text{and} \quad y' = y + \Delta y(x)$$

where $x'$, $y'$ are the corrected image coordinates; $x$, $y$ are the measured and pre-processed image coordinates; $\Delta x(x)$, $\Delta y(x)$ are the corrections as a function of the x coordinates, which can be approximated by an algebraic polynomial, such as

$$\begin{aligned} \Delta x(x) &= a_o + a_1 x + a_2 x^2 + \ldots a_n x^n \\ \Delta y(x) &= b_o + b_1 x + b_2 x^2 + \ldots b_m x^m \end{aligned} \qquad (1)$$

The corrected image coordinates were then introduced into the affine transformation equation, so that

$$\begin{aligned} X &= A_1 + A_2\ [x+\Delta x(x)] + A_3[y+\Delta y(x)] \\ Y &= B_1 + B_2\ [x+\Delta x(x)] + B_3[y+\Delta y(x)] \end{aligned} \tag{2}$$

If the image and the ground coordinate systems are nearly parallel, the coefficients $A_3$ and $B_2$ are small and their products with the correction terms can be neglected. A substitution of (1) into (2) yields

$$\begin{aligned} X &= A_1 + A_2x + A_3y + A_4x^2 + A_5x^3 + A_6x^4 + \ldots A_{(n+2)}x^n \\ Y &= B_1 + B_2x + B_3y + B_4x^2 + B_5x^3 + B_6x^4 + \ldots B_{(m+2)}x^m \end{aligned} \tag{3}$$

Transformation formulae of various degrees can now be set up, depending on the degree of the polynomial selected for $\Delta x(x)$ and $\Delta y(x)$. Two such versions were tested [Szabo, 1980]. In the one, the first four terms of (3) were included for both X and Y. This eight parameter transformation was named G8. In the other, terms one to six were used for X, while Y remained as before. This version was called G10.

First, each strip was transformed in its full length in one operation (long strip mode); then about one half of each strip was transformed as a unit (short strip mode). In each case, 14 regularly distributed points were used as control to compute the transformation parameters and the rest of the points were employed as check points.

For the sake of comparison, each long and short strip was also processed by similarity affine and projective transformation and by the following two polynomial functions: (The same control points were used in each transformation).

$$\begin{aligned} X &= A_1 + A_2x + A_3y + A_4xy + A_5x^2 + A_6x^2y + A_7x^3 \\ Y &= B_1 + B_2x + B_3y + B_4xy + B_5x^2 + B_6x^2y + B_7x^3y \end{aligned} \tag{4}$$

and

$$\begin{aligned} X &= A_1 + A_2x + A_3y + A_4xy + A_5x^2 + A_6x^2y \\ Y &= B_1 + B_2x + B_3y + B_4xy + B_5x^2 + B_6y^2 \end{aligned} \tag{5}$$

The above polynomials were successfully used for the processing of imagery recorded by other radar system configurations and were not specifically selected for the imagery at hand. Formula (4) was suggested by Derenyi [1974], while (5) was used by Laberl [1972].

Occasionally, all information needed for earth curvature correction and slant-to-ground range reduction may not be available. In this case a correction term can be added to the y image coordinates, which is a function of y, such as

$$\Delta y(y) = c_o + c_1y + c_2y^2 \tag{6}$$

For a nearly parallel image and ground coordinate system this will result in the addition of a $B_5y^2$ term to the Y polynomial. Hence, the number of coefficients were increased by one in each version of the transformation. The new formulae were identified as S9 and S11 [Szabo, 1980].

## PRESENTATION AND DISCUSSION OF RESULTS

Tables 1 and 2 present the root mean square (RMS) errors of position for the check points after the various types of transformation. The results in Table 1 were obtained with pre-processed image coordinates, while Table 2 shows the outcome of the transformations when uncorrected measurements were used. In each case 14 control points were employed. The RMS values tabulated here, are weighted averages pertaining to the three strips. There were a total of 118 check points available for the three long strips and a total of 82 check points for the short strips. All values are shown in metres.

TABLE 1: RMS OF DISCREPANCIES IN POSITION AT CHECK POINTS (in metres); DATA REDUCED TO GROUND RANGE.

| | Transformations | | | | | | |
|---|---|---|---|---|---|---|---|
| Strip | Sim | Aff | Proj | Eq. 4 | Eq. 5 | G8 | G10 |
| Long | 27.8 | 25.8 | 22.2 | 19.7 | 22.2 | 19.4 | 19.4 |
| Short | 16.0 | 12.0 | 11.7 | 11.3 | 11.6 | 11.5 | 9.9 |

Notations: Sim = similarity; Aff = affine; Proj = projective; Eq. 4 and Eq. 5 = equations (4) and (5) respectively in the text.

TABLE 2: RMS OF DISCREPANCIES IN POSITION AT CHECK POINTS (in metres); DATA IN SLANT RANGE

| | Transformations | | | | | | |
|---|---|---|---|---|---|---|---|
| Strip | Sim | Aff | Proj | Eq. 4 | Eq. 5 | S9 | S11 |
| Long | 58.6 | 35.1 | 32.7 | 29.0 | 22.6 | 21.8 | 21.8 |
| Short | 43.7 | 19.8 | 19.2 | 19.4 | 12.1 | 11.9 | 10.3 |

Systematic errors of considerable magnitude were present in the uncorrected radar imagery. This fact is clearly illustrated in Table 2 by the large errors remaining after similarity transformation. Affine transformation reduced the errors considerably and further, significant improvements were achieved by polynomial transformation. However, the best results were attained when the measurements were also preprocessed (see Table 1). Projective transformations had only a marginal advantage over the affine transformation. This is understandable, since radar imagery is not a central perspective.

A comparison between the results obtained with the various polynomials indicate that the solution is rather sensitive to the form of higher order terms. Hence, an increase in the number of terms does not necessarily improve the accuracy of the transformation.

Significant improvement was gained in the results when the length of the strip processed as a unit was reduced.

The cartographic potential of SAR imagery can best be examined by relating the results to map accuracy standards. Widely accepted standards in North America require, that on Class A maps 90% of well defined features shall be located within 0.5 mm of their true position. Position accuracies at the 90% confidence level attained with pre-processed measurements and G10 transformation are 0.23 mm and 0.12 mm for the long and short strips respectively. Hence, it is possible to extract planimetric information with digital mapping techniques from this particular SAR imagery which will satisfy Class A mapping standards at scales of 1:100000 to 1:50000.

## CONCLUSIONS AND RECOMMENDATIONS

Within the limits of the available information the following conclusions were drawn:

- The eight parameter transformation G8 is regarded as the optimum method for the planimetric transformation of SAR imagery which was recorded in ground range presentation or was corrected accordingly. An extension of the polynomial to 3rd and 4th order terms in X-direction leads to appreciable improvements of the results only in short strips with rather dense control. The optimum method of transformation for slant range recording is polynomial S9 for long strips with sparce control and S11 for short strips with dense control.

- For ground range recording of a short strip with dense control, affine transformation can yield results which closely watch those obtained with polynomial G8. In other cases, however, especially when slant range remains uncorrected, polynomials provide far superior results.

- It is highly recommended to correct for slant range distortion before transformation. Data reduced from slant to ground range, generally yields better results with G8 transformation than the uncorrected data with S11 transformation.

- SAR-580 imagery has definite potential as a source of information for the revision of 1:50000 scale Class A maps, when digital mapping techniques are employed.

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