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Image Rectification and Registration

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Abstract: This paper discusses various approaches to geometrically transform digitized images of different sensors. The main problems of image matching are shown and some possible solutions are pointed out.

1 INTRODUCTION

One significant task of photogrammetrists in the remote sensing area is to geometrically transform images of various sensors, which can be of multitemporal, multispectral or of symbolic nature (Leberl, 1983, Göpfert 1983). On the other side there exists a demand for automatic close range real time stereo measuring systems for industrial applications. Traditional tools for geometrical processing, like orthophotoprojectors, rectifiers or stereoplotters are not well suited to deal with digital images generated by non-photographic data acquisition systems.

2 RECTIFICATION OF DYNAMIC IMAGES

Konecny (1976) has divided the mathematical models for treating with line scan (dynamic) images into four groups:

A) Deterministic, without using a geometrical sensor model
   a) Polynomials
   b) Splines
B) Stochastic, without using a geometrical sensor model
   a) Weighted mean
   b) Moving averages
   c) Multiquadric interpolation
   d) Least squares interpolation
C) Deterministic, using a geometrical sensor model

  - a) Polynomials to model time varying orientation elements
  - b) Fourier series to model time varying orientation elements
- D) Stochastic, using a geometrical sensor model
  - a) Gauß-Markov processes to model time varying orientation elements

Newer examples for realization of the mentioned methods are presented in Diarra (1982), Jansa (1983), Schuhr (1982) or Wiesel (1981).

2.1 RECTIFICATION OF AIRBORNE SCANNER DATA

Because of the high frequency dynamic variation of airborne sensor orientation elements, elaborate (Groups C or D) mathematical models have to be applied, if

- terrain is hilly
- data sets are large
- required accuracy is high (better than +5 pixels)
- number of control points is small

Schuhr (1982) compared several rectification models:

A) global polynomials, no sensor model
B) collinearity equations, polynomials to model orientation element variation, degrees 1 - 5, 1 orientation element set per scan line
C) collinearity equations, Fourier series to model orientation element variation, 1 orientation element set per scan line
D) like B) plus additional parameters
E) like C) plus additional parameters

Applying these methods to three different data sets (Bendix MMS optical-mechanical scanner) of different size (from 1100 to 3200 scan lines), the results can be grouped into 3 classes:
First, methods B/C, second, methods D/E and third, a special case of B. There was no significant difference in accuracy between various polynomial degrees of methods B/D or Fourier series degrees of methods C/E. Additional empirical interpolation parameters to eliminate intraline effects reduced errors of one data set from ±15 pixel RMSE to about ±4 pixel RMSE, while results of another data set could not be improved further from about ±3 - ±4 pixel RMSE.
Yet a significant accuracy improvement could be achieved by introducing projection center coordinates of a photogrammetric camera, computed via a bundle adjustment, which was mounted on the scanner platform, as additional observations. Root mean square errors of about ±1 pixel could be measured at independant check points after an additional stochastic interpolation of residuals at control points using the weighted mean method.
It should be mentioned, that an interpolation using global polynomials (group A) led to similar results as methods B-E for a short data set (1100 lines) acquired over flat terrain.

One drawback of optical-mechanical scanners, non-constant orientation elements while scanning one line, will be overcome by the newer CCD-scanners (Hofmann et. al. 1982), which simultaneously record one line at a time.

2.2 SPACEBORNE SENSORS

Procedures to process LANDSAT data are well known and described often in literature (see for example Bähr, 1976). For most applications, global polynomials of second or third degree based on 12 to 25 well distributed ground control points per scene yield RMS errors of about ±0.5 to ±1.0 pixel.
A better and more general approach is, to recover all parameters of satellite position and sensor attitude using parametric models (Mikhail, 1984). Simulation studies of Mikhail (1984) show, that subpixel rectification is possible, if ground control points (GCP) can be identified to sub-pixel accuracies. Roll, Pitch and an uncertain position of the sensor along the orbit contribute the largest errors to satellite images.
Larsen (1982) tried to improve GCP accuracy by correlating LANDSAT MSS data with digitized aerial photographs of higher spatial resolution. Friedmann et al. (1983) propose a precision rectification method, based on a Pseudo-Physical Orbit-Attitude model of the spacecraft. The roll-, pitch-, yaw- and height parameters are estimated from ground control points using a recursive filter. Results are presented, which prove that 10 (ten) adjacent LANDSAT-2 scenes of one orbit could be precision rectified (±1 pixel RMSE) using only 4 (four) ground control points.
If we look at newer earth observing spacecrafts, we have to consider LANDSAT-4 Thematic Mapper (TM) and the french SPOT satellite. Göpfert (1983) estimated, that terrain height differences of 230 m (TM) and 266 m (SPOT) will cause rectification errors of 1 pixel. Therefore a Digital Terrain Model (DTM) has to be used for precision rectification of TM and SPOT data acquired over moderately hilly terrain. Only the Collinearity equation approach seems to be able to relate a DTM to the high resolution spaceborne data. The accuracy of the DTM should be better than ±115 m to ±133 m (Göpfert, 1983).

3 RECTIFICATION OF DIGITIZED PHOTOGRAPHS

To geometrically transform analog images by digital image processing techniques, images have to be scanned by an analog to digital converting device, like a microdensitometer, generating a matrix of grey scale values (pixels). Pixel size and amount of data depend on image size and desired quality of the rectified image.
Several examples exist for applying digital image processing techniques to orthophoto production (Bie 1983, Keating 1979, Konecny 1979, Kreiling 1975, Kreiling 1976, Peled 1984, Wiesel 1981, Wiesel

1983).

Mathematical procedures are well known; required are the orientation elements of the input image, a digital model describing the object surface and a pixel matrix of the input image. Computing the resultant orthophoto is straightforward applying collinearity equations.

The most important problem of digital orthophoto production is of economical nature. Scanning an image with a small aperture generates very large data sets, which are costly to process but will allow for high quality orthophoto products (Table 1).

pixel size (aperture) (micrometers)	generated data (megabytes)
12.5 x 12.5	323
20 x 20	126
25 x 25	81
50 x 50	20
100 x 100	5

Table 1: Data generated by scanning a 23 x 23 cm photograph

The necessary scanning resolution can be estimated by defining the enlargement ratio between photograph and orthophoto and the required resolution in the orthophoto scale. In the case of reproducing grey scale images by screening and printing, an orthophoto pixel size of 0.167 mm is sufficiently small to generate a halftone map of good visual quality (Kloppenburg 1972, Schmidt 1975, Wiesel 1983). At an enlargement ratio of 2.5 between input image and orthophoto the input image has to be scanned with a pixel size of 50 micrometers.

4 RESAMPLING

After geometrical analysis, interpolation and adjustment of geometric transformation parameters, scanner image data has to be physically transformed into another sample grid using the evaluated parameters. This step, reconstruction of the rectified image matrix, is called resampling. Resampling techniques and their influence on rectification results have not been studied very deeply in the photogrammetric community. Stucki (1979) reviewed current resampling algorithms comparing speed and performance for continuous-tone text and continuous-tone portraits (Table 2). He summarized, that third order interpolation functions (bicubic or lagrangian) work best for all studied cases, but first order (bilinear) performs well for continuous-tone images at significantly lower cost. Pratt (1978) theoretically estimated errors generated by common resampling methods relative to the ideal sinc interpolation filter (Table 2).

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Resampling-technique	Interpolation neigbourhood Pixel	Number of Additions/ Multiplicat.	Error (Pratt) %	Performance (Stucki) Decibel
NN	1 x 1	1	15.7%	23.1 db
BL	2 x 2	8	3.7%	33.2 db
CS	4 x 4	110	0.3%	33.0 db
LP	4 x 4	80	?	34.1 db

NN	Nearest Neighbour	(Zero-order)
BL	Bilinear interpolation	(First-order)
CS	Cubic spline	(Third-order)
LP	Lagrange polynomial	(Third-order)

The results of Stucki should be interpreted as a description of the average performance of the interpolator; they are valid only for the type of images with special spatial and spectral properties Stucki worked with.
Mulder (1982) reported on a special resampling approach, a langrangian 3-point operator, which de-convolves the oversampled LANDSAT in-scan data. He recommended to design resampling operators based on spatial local features instead of spectral criterea, avoiding artefacts, like rings surrounding bright spots etc. The most severe problem of all higher order resampling operators (Table 2) is the very high amount of computing time needed. This could be overcome by the use of special parallel processors like the NASA MPP (Gerritsen 1983), pipeline processors (Kazmierczak 1980) or commercially available array/vector processors.

5 REGISTRATION

Registration is defined as relating patches of overlapping images together to obtain data sets with well defined geometrical relations. Registration is in use for stereo image correlation (Claus 1983), point transfer in photogrammetric measuring devices (Ackermann 1983, Förstner 1984), measuring of target coordinates in digital images (Mikhail 1983), overlaying of multi sensor images for interpretation purposes (Ehlers 1983, Wiesel 1981).
Registration tasks can be divided into several cases:

A) Registration of spatially and radiometrically similar images. (Stereo image correlation of flat objects, point transfer, certain multi temporal and multi sensor images)
B) Registration of spatially similar and radiometrically different images.
(multi temporal images, certain multi sensor images)
C) Registration of spatially different and radiometrically similar images.
(image sequences, industrial close range stereo measurement of 3-D objects)

D) Registration of spatially and radiometrically different images.
(multi sensor images, image to map registration)

Task A is in most cases solvable using standard correlation techniques (Claus 1983, Ehlers 1983, Förstner 1982, Förstner 1984, Makarovic 1980, Mikhail 1983). Recent investigations of Ackermann (1983), Förstner (1982) and Mikhail (1982) proved that it is possible to achieve point location errors using correlation techniques less than ±0.1 pixel RMSE. Target location precision ist determined by three parameters (Förstner 1984):

- image noise variance
- number of pixels involved
- variance/covariance of the gradient image

Considering rule 2 above it is clear that one-dimensional epipolar correlation procedures (Claus 1983, Kreiling 1976) will be of poorer parallax accuracy performance than other techniques using two-dimensional correlation patches.
Ackermann (1983) presented a modified ZEISS PLANICOMP Analytical plotter equipped with CCD-Video-Cameras for precision measuring of well defined image targets. At an actual resolution of 20 micrometers in the image plane a locating precision of about +1 micrometer RMSE has been achieved in first experiments. Planned applications are in all areas of x- and y-parallax measurement.
Case B raises qüite another sort of problem. The main task is to identify (and than to locate) similar parts of multi sensor images. One solution is to preprocess data, extracting invariant features. Edges are strong candidates (Wiesel 1981), they are computable using well known edge extracting operators (e.g. Sobel, Kirsch, Lapalce, Roberts etc.). If images are very dissimilar, segmenting techniques, known from pattern recognition, are strongly needed (Bargel 1983, Kestner 1983). Segmenting is defined as extracting image areas of similar properties, e.g. brightness, texture, shape, colour. After extracting these areas (segments) matching will be performed by matching segments.
Cases C and D can be discussed together. Pattern recognition techniques seem to be the only solutions to register very dissimilar images.

Davies (1979) described a method for correlating rotated images with different scales using gradient vector sums. Wong (1978) extracted 7 invariant statistical moments out of multi sensor, multi scale images for registration purposes. Horn (1983) overlayed a DTM to a LANDSAT image by generating a synthetic image out of the DTM applying a luminance/reflectance model. Kropatsch (1981) and Leberl (1982) extracted objects from aerial photographs and LANDSAT scenes, identified and matched them with the content of a digital map database. Cheng (1983) extracted edges from a close range image pair, segmented, labeled and computed relations of image structures, matching image parts using relational attributes like "parallel", "antiparallel", "adjacent" etc. Cheng et. al. (1983) applied a local operator to two images, which detected two sets of "corners" characterizing them by position, orientation, sharpness of angle and contrast. A relaxation process is then used to compute shift vectors and rotation angles. The method yielded good results for images which contained enough features.

6 CONCLUSION AND SUMMARY

Image rectification procedures are now of more rigorous nature than some years ago. A tendency can be watched to apply stronger mathematical models to achieve sub-pixel accuracies or to process higher resolution data.
In the image registration area there are two "mainstreams":

- Precision locating of well defined image targets

and

- matching of very dissimilar multi sensor, multi temporal, multi resolution images by pattern recognition techniques.

It will be a demanding challenge, to integrate both approaches trying to automate all steps of image rectification and matching, to build real intelligent registration systems.

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