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RESUMO-NOTAS/ABSTRACT-NOTES

In several applications satellite imagery is a very important tool for cartographic recover. With LANDASAT (MSS and TM) data it is possible to work only with planimetric information. Now the images from the French satellite SPOT, in oblique view, permit DTM (Digital Terrain Model) generation, both in the analytic and digital domain. In Brazil, the Institute for Space Research, and the IBM Rio Scientific Center are developing a project, in the digital domain, for this purpose, composed of seven modules: 1- radiometric correction, for image equalization; 2- resampling in epipolar geometry, from the geometric modelling; 3- automatic correlation, to generate the parallax data; 4- altimetric restitution from parallax data; 5- DTM interpolation and evaluation; 6- synthetic image generation from SPOT data; and 7- DTM data matching. Three areas were chosen, in order to check the accuracy of the mathematical model with respect to the data from the topographic maps covering the areas.

OBSERVAÇÕES/REMARKS

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RESUMO

Em muitas aplicações, as imagens de satélite são uma ferramenta importante para a restituição cartográfica. Com dados LANDSAT (MSS e TM) é possível trabalhar somente com informações planimétricas. Agora, as imagens do satélite francês SPOT, com visada oblíqua, permitem a geração de DTM (Modelos Digitais de Terreno ou "Digital Terrain Model "), em ambos os domínios, digital e analógico. No Brasil o Instituto de Pesquisas Espaciais e o Centro Científico Rio da IBM Brasil, estão desenvolvendo um projeto conjunto, no domínio digital, com este propósito, composto de sete módulos: 1- Correção radiométrica, para equalização das imagens; 2- Reamostragem em geometria epipolar, a partir da modelagem geométrica; 3- Correlação automática, para gerar dados de paralaxe; 4- restituição altimétrica, a partir de dados de paralaxe; 5- Interpolação e avaliação dos DTM's; 6- Geração de imagens sintéticas, a partir de dados SPOT; e 7- Casamento de dados em DTM. Três áreas de estudo foram escolhidos, a fim de avaliar a precisão do modelo matemático em relação aos dados das cartas topográficas das áreas em questão.

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DTM GENERATION FROM SPOT STEREOSCOPIC PAIR

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Abstract

In several applications satellite imagery is a very important tool for cartographic recover. With LANDSAT (MSS and TM) data it is possible to work only with planimetric information. Now the images from the French satellite SPOT, in oblique view, permit DTM (Digital Terrain Model) generation, both in the analytic and digital domain. In Brazil, the Institute for Space Research, and the IBM Rio Scientific Center are developing a project, in the digital domain, for this purpose, composed of seven modules: 1- radiometric correction, for image equalization; 2- resampling in epipolar geometry, from the geometric modelling; 3- automatic correlation, to generate the parallax data; 4- altimetric restitution from parallax data, 5- DTM interpolation and evaluation; 6- synthetic image generation from SPOT data; and 7- DTM data matching. Three areas were chosen, in order to check the accuracy of the mathematical model with respect to the data from the topographic maps covering the areas.

1. INTRODUCTION

The growing demand for satellite imagery has contributed to the constant improvement on the design of orbital sensors. The application field for these images is wide, especially into the geosciences.

The first orbital systems could only look at the nadir, thus the information was planimetric. With the launching of the French satellite SPOT, with side-looking capabilities, it became possible for the first time to build stereoscopic models of the Earth's surface. The users may ask the satellite to be programmed to look to a particular region with a nadir angle up to -27 or +27 degrees. At the maximum angles, the base-height relation is slightly larger than 1.

The oblique view also permits to visit the target area more frequently, in order to follow dynamic phenomena like floods, forest fires, etc.

In order to generate DTM's from SPOT stereoscopic pair images, the Brazilian Institute for Space Research (INPE), and the IBM Rio Scientific Center (RCC-IBM Brasil) have signed an agreement. The main objectives of the joint project detemined by the Agreement are: to research, to test and to validate algorithms to allow the altimetric information to be extracted from SPOT stereo images, from the sensor HRV (Visible High Resolution sensor).

Initially, it is necessary to acquire the stereo images, and the ancillary data associated. Then, the project is divided into seven modules:

- Module 1 - Radiometric Correction: its objetive is to eliminate the radiometric distortions embedded into the image acquisition process. Such distortions are produced by atmospheric attenuation and refraction, the presence of haze, the different angles between the sun, the target normal and the satellite, the different solar azimuth and elevation angles.

- Module 2 - Epipolar Resampling: is designed to obtain the resampled image according to quasi-epipolar lines, thus the parallax is concentrated almost along epipolar lines. This procedure speeds-up the automatic correlation process among the stereoscopic image pair.

- Module 3 - Automatic Correlation: determines the homologue grids, in which one image of the stereopair is related to the other. From these grids it is possible to recover the image altimetry.

- Module 4 - Altimetric Restitution: generates an altitude matrix of the homologue grid nodes, with respect to a cartographic projection system. The matrix is obtained from the homologue grids, and parameters from the satellite image.

- Module 5 - DTM Intepolation and Evaluation: produces regularly spaced distributed data, on the cartographic projection space, with different scales, and evaluate them. The data are shown on a rectangular regular grid. The evaluation is with respect to another DTM obtained from cartographic charts of the test areas.

- Module 6 - Geometric Correction: corrects the HRV-SPOT image, oblique view, to level 3 specifications.

- Module 7 - DTM visualization: presents the DTM data on a monitor screen or plotter. It is envisaged isolines and tridimensional perspective presentations.

Next sessions will describe all the above modules in detail, and, at the end, final comments and conclusion will be drawn. The work still is under way, but for the moment the progress is promissing.

2. RADIOMETRIC CORRECTION

The automatic correlation assumes that the image stereo ·pair is radiometric equalized. Ideally the same target should present the same grey level on both images. Unfortunately, on the SPOT images, many factors contribute for different grey levels on the same target. The oblique view is responsible for part of the problem. For instance, the stereo pair is acquired on different days, from different orbits. The atmospheric conditions are likely to be diverse on different days. The solar incidence also is different. Also the angle sun/target/satellite is very different from both images due to the right or left side-looking. These problems could be minimized with a satellite that would have a forward-backward look, but this is not the SPOT case.

This module then attempts to correct the radiometric discrepancies between the image pair, by correcting the atmospheric effects, haze removal, and solar azimuth, elevation and incidence. The combination of all these effects is planned to be put into a convolution filter to be applied to the images.

3. EPIPOLAR RESAMPLING

The search for homologue points is normally made in two directions. If the window in the vicinity of a point on image 1 has dimension N x N, and the search area on image 2 has dimension M x M, then there exist (M-N+1)(M-N+1) windows of dimension N x N in the search area. One of then is closely related to the window on image 1. It is necessary to calculate the correlation for all possible windows of the search area. However, the computational cost of the correlation is very high.

For DTM generation from SPOT stereo pairs, the correlation computation has to be performed millions of times. Thus, it is a must to try to reduce these computational costs. For side-looking images, the ground relief makes the correlation computation even more difficult.

A method for reducing this computational cost is the epipolar resampling. Two new images are generated, such that the relief distortions are concentrated nearly along lines. The main advantage is that all the points along a line of image 1' have its homologues almost over one line over image 2'.

Masson d'Autume (1) defines this quasi-epipolar lines in a way similar to the epipolar lines from aerophotogrammetry. After this resampling, the number of windows to be searched for reduces to (M-N+1).

For SPOT images the lines are quasi-epipolars, then, the search cannot be made on just one line. Normally the search is made on three lines, one above, one below, and the quasi-epipolar.

Once the quasi-epipolar direction is defined, the resampling matrices are determined. These matrices relate the epipolar images to the raw images. Based on these matrices new images are created, in which the parallaxes due to the relief are almost along the lines.

4. AUTOMATIC CORRELATION

A key module on this process is the automatic correlation. The computational cost of this module is very high, making it a bottleneck to the whole process. It is not enough to have an algorithm for automatic correlation, this algorithm have to be very efficient, to be practical for a production system.

It is not easy to perform automatic correlation, in general. However, if one wants to register side-looking images, with opposite views, there are even more problems.

Due to geometric relations from oblique views, the terrain relief and the point of view produce a situation in which a pixel in one image may correspond to many pixels on the other. The relief may produce also invisible areas on the images, due to the angle of sight. Depending on the terrain relief, this problem may cause a significant reduction on the correlation precision.

The first step is to define the superposition area between the images. It is possible to use the navigation model for direct mapping of the geometric correction developed by Machado e Silva et al. (2). Once defined the superposition area, the histograms, and the histograms statistics (average and standard deviations) for this region are calculated. It is possible then to the operator to take some decisions, like to equalize the images or to binarize them, according to Guichard (3).

The equalization may be performed by means of a linear transformation, or a non linear transformation. In the first case the idea is to force both images to have te same histogram statistics, and can be achieved by means of a look-up table (LUT). In the second case, the objective is to modify both images to make them have the same histogram.

Image binarization only will be necessary if the equalization would not yield a good correlation precision. In order to take the decisions, the operator may take advantage of control points to evaluate the correlation results.

To register one image into another, a sample points grid of equally spaced points is defined over one of the images. For each grid break-point on the first image it is determined by correlation the homologue on the second image. The correlation result is going to generate the homologue points, that will be irregularly distributed over that second image.

The density of the matrices is going to determine the DTM precision, dependent upon the relief type, and the stereoscopic pair base-height relation (4). It is vey important to choose a proper interpolation to keep the errors within acceptable limits, when regularizing the second image.

5. ALTIMETRIC RESTITUTION

The main objective of this module is to evaluate the several altimetric restitution algorithms. The evaluation is with respect to the precision of the results. No image processing is needed, since the input data are the homologue points matrices, the image, and satellite parameters (ephemeris, atitude, etc).

It is possible to define the altimetric restitution model from the image coordinates (line and column), and control points. The restitution may generate absolute or relative altitudes. On the later case, to obtain the absolute altitude it is used a control point.

The absolute restitution defines the relative altitude related to an Earth reference surface, from vectors associated to a point position on each image. In this process it is necessary to use control points to eliminate the distortions caused by ephemeris imprecision.

Two problems are caused by this ephemeris imprecision: the homologue views become reverse, and the variations on the satellite position cause distortion on the altitude calculations.

On the first case, if the satellite position is considered to vary linearly on a short time interval, then a third unknown is created on the equations system. On the second case the distortion is constant for all the image pixels, and the use of control points allows one to eliminate it.

The relative restitution uses parallaxes defined on the homologue points correlation. The difference along the columns between two grid nodes is not constant for the two images. The difference, between such differences, defines the parallax, that permits the determination of the altitude difference between these two nodes (4). At the end, control points will allow to transform these altitude differences data into absolute altitudes for an Earth's frame of reference. It is planned to investigate the results from both approaches with respect to the precision expected.

The algorithm evaluation will be made in two phases. Initially, all the tests will be made over the control points. Later, the altimetric data matrix will be evaluated.

The altimetric data matrix will be referenced to a regular grid, on the epipolar image space. In other words, for each matrix point it will be known the altitude and the epipolar image coordinates. The altitude data will be referenced to the Earth's reference frame, if possible through coordinates of this projection system. To obtain that, it is necessary to use the epipolar resampled matrix, which permits access to the raw image dominium. The photogrammetric model for SPOT level 3, allows one to relate the raw image data with any cartographic projection system, according to Machado e Silva and Barbosa (5).

The photogrammetric model related to the SPOT level 3 takes into account the relief effects, thus the altitude matrix, obtained from the restitution model is used to eliminate these distortions. Control points are also employed to assure the perfect match between the altitude data and the cartographic projection system.

It should be noticed that the matrix, when referenced to the cartographic projection system does not presents a regular spacial distribution, and its inverse is the resampled matrix base, for geometric correction.

6. INTERPOLATION AND DTM EVALUATION

Interpolation is used all along the project. This module studies the several methods for each application. The matrix obtained from the altimetric restitution is not regularly spaced along the cartographic projection space. Two different paths can be followed: a sample triangulization, or its regularization in constant intervals. As the initial distribution is similar to a rectangular regular distribution, it was decided to prefer this regularization. From now on the matrix becomes a Digital Terrain Model (DTM).

On this module several interpolators will be tested, as far as computational cost and precision performance. Some of the interpolators to be tested are: linear, polinomial, cubic splines, B-splines, etc. After the interpolation a DTM final evaluation will be made. In order to do it, topographic charts of the study region will be used. The largest available scale will be preferred. The charts contour lines will be digitized, generating a DTM with the same characteristics of the DTM obtained from the HRV-SPOT digital stereoscopic images altimetric restitution.

The comparison to be made are among the nodes on the two DTM's the one from altimetric restitution, and the one obtained from topographic charts from the area under study. A histogram of the residues will be made. Grabmaier (6) suggests that the calculations of the average and the standard derivations of the residues also should be performed.

Another possible analysis is concerned to the normalized error, as a function of the node altitude from the topographic charts obtained DTM. The residue is divided by the node altitude, thus it is obtained the residue by altitude unit.

It should be warned that there is an error associated to the DTM from the topographic charts, due to the error associated to the production of these charts.

7. GEOMETRIC CORRECTION

The Geometric Correction is the last image processing module, for the whole process of obtaining DTM's from SPOT stereo pair images. The matching of geometrically corrected images with DTM data allows the generation of synthetic images with a three dimensional perspective view.

The resampled matrix used for the Geometric Correction is a function of the altitude matrix generated from the altimetric restitution (7). The resampled matrix does not need to be as dense as the altitude matrix (8). This matrix inversion may be made by the traditional polynomial mapping method (8), or be inverted by direct mapping iteractive processes.

After the image resampling, the corrected image is evaluated, from the control points, in order to verify its geometric quality. Certain parametes, as anisomorphism and lenght variation should be estimated and compared with the SPOTIMAGE (French Agency responsible for SPOT exploration and standardization) specifications.

8. DTM VISUALIZATION

The visualization can be achieved by means of contour line maps or three dimensional (3D) perspective views. On the latter case, as a wire-mesh or a solid model. The 3D models can be viewed from different points of view. The computer output is either a plotter or a computer monitor screen.

Combining the DTM data from altimetric restitution with the DTM from the topographic charts, using different colors for each, it is possible to view the differences. Also it is possible to plot the difference model, based on the residues. Finally, with the solid model it will be possible to fly over the test region, by changing the point of view.

9. CONCLUSIONS

At the end of the project, the team involved will be able to dominate the methodology to obtain DTM's from SPOT stereoscopic image pairs. As an off-spring, new associated techniques for image processing, on several levels will be acquired.

Some topics closely related to the main project objective also will be studied as: atmospheric correction, radiometric correction, satellite images automatic correlation, among others.

The use of triplets, in order to improve the restitution precision (9), will be considered, in spite of the added computer cost. The use of a vertical image is important, since the side-looking views present invisible areas due to the relief.

The computer facilities to be used are the Rio Scientific Center IBM-3090, and the IBM-PC-based image processing workstation SITIM, developed by INPE. The latter will be maily used for display the results and algorithms tests, while the first system will be used for a prototype of the whole system. Another benefit will be the knowledge to be obtained from all the phases of processing HRV-SPOT images. The result of this work is similar to level 4 processing. The methodology to be developed may be employed in conventional aerial photographs, and terrestrial photogrammetry.

The aerophotogrammetry is a field in which the epipolarity is easily achieved. On terrestrial photogrammetry, the DTM's of historical buildings façades is already in use. The altimetric precision and spacial resolution should be compatible with the problem under study.

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