AN INTEGRATED SOFTWARE SYSTEM FOR GEOMETRIC CORRECTION OF LANDSAT MSS IMAGERY

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ABSTRACT

An integrated software system for geometric correction of LANDSAT imagery is described. This system includes all phases of processing, from receiving a raw CCT (computer compatible tape) to the generation of a corrected CCT (or UTM mosaic). Emphasis is placed on a model which needs few control points, and on the creaton of a ground control point library for Brazil. The system comprises 8 modules: a) Management: control of the processing flow; b) Image Parameter Determination: calculation of satellite ephemeris and attitude parameters, differing LANDSAT-4 from LANDSAT-1,2 and 3; c) CCT Aquisition: generation of uncorrected files from raw CCT data; d) GCP Library: creation, management and maintenance of a ground control point library; e) Image Geometry Equations: determination of the image correction equations, using attitude and ephemeris parameters and existing ground control points; f) Resampling: generation of corrected LANDSAT file, using the equations determined beforehand; g) Mosaic: union of LANDSAT scenes to produce and UTM mosaic; h) Output CCT Generation: generation of output tape, in super-structure format. The system will be utilized for the generation of corrected CCTs and UTM mosaics, for the users of LANDSAT images received by the Brazilian LANDSAT receiving station, managed by INPE.

I - INTRODUCTION

The LANDSAT series of satellites has caused a tremendous impact on the surveying and management of earth resources. In a number of areas such as Geology, Agronomy and Forestry, LANDSAT imagery has proven extremely useful for a great number of analysis. In many other applications, however, it is necessary to generate geometrically corrected images; such is the case of mapping and change detection applications, as well as the integration of LANDSAT images into a geographic information system. Mapping applications are specially important in countries such as Brazil, which has large portions of its territory poorly mapped.

This work presents an integrated software system designed to produce geometrically corrected LANDSAT MSS imagery in an operational way. It was done at Brazil's Instituto de Pesquisas Espaciais (Institute for Space Research), which is the institution responsible for receiving and disseminating LANDSAT imagery in Brazil. The products to be generated by the system are corrected CCTs and digital mosaics in the UTM projection. Such products will be used to produce 1:250000 charts for the whole country, specially for the Amazon region, a large tropical forest of very difficult access which covers 40% of Brazilian territory.

The development is being done in accordance to the most advanced software engineering techniques, which are being applied in a large number of institutions, with excellent results (Beck and Parkins, 1983). Therefore, the system is divided into 8 modules, each one carrying out a specific task, as described below:

a) Module 0 - MANAGEMENT: concerns the specification of the taks to be done by the system, as well as checking the completed ones.

b) Module 1 - IMAGE PARAMETER DETERMINATION: concerns the processes of obtaining the platform's attitude and ephemeris based only in the satellite's telemetry data.

c) Module 2 - CCT ACQUISITION: concerns the processes of obtaining and generating the image file to be corrected.

d) Module 3 - GCP LIBRARY: concerns the creation, management, maitenance and visualization of a ground control point library. Includes also GCP generation for the image to be corrected.

e) Module 4 - IMAGE GEOMETRY EQUATIONS: concerns the determination of the image correction matrix ("break-points") from the platform parameters (attitude and ephemeris), using existing GCPs to refine the model.

f) Module 5 - RESAMPLING: obtains the correct LANDSAT image from the correction matrix derived from the previous module and the original image.

g) Module 6 - MOSAICKING: realizes the union of corrected LANDSAT scenes to obtain a combined image which contains the area of interest in the UTM projection.

h) Module 7 - OUTPUT CCT GENERATION: delivers a corrected CCT in a superstructure format, as recommended by LTWG.

The processing flow of the system is illutrated in Figure 1.

In what follows some general considerations about the geometric correction problem are made, and a description of each one of the system building blocks is given.

II - THE GEOMETRIC CORRECTION PROBLEM

Spaceborne imagery is troubled by a variety of error sources which introduce geometric distortions. These errors may be classified in internal and external ones. Internal errors are those caused by the MSS sensor inherent distortions, and

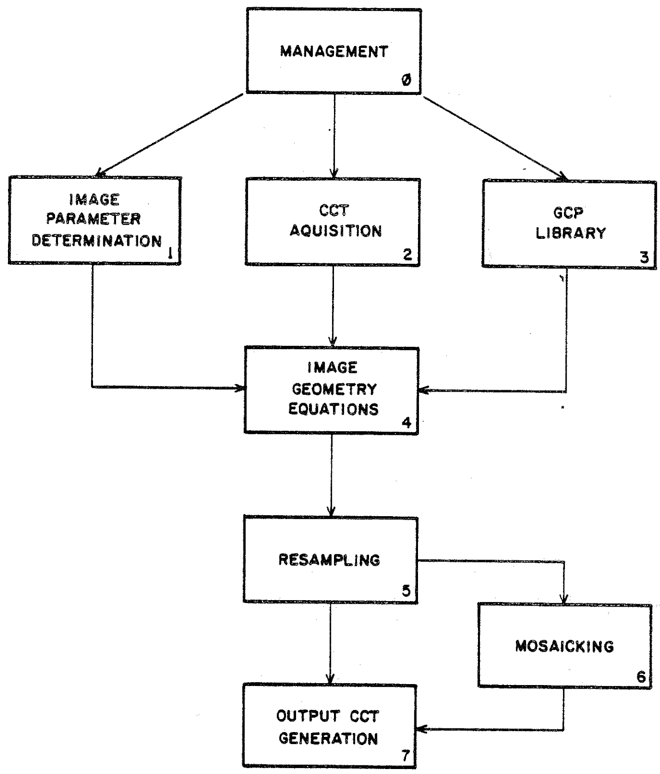

Figure 1 - Processing Flow of the System

include mirror scan nonlinearities and detector sampling delays. The external errors are due to the platform effects and the imaging conditions, and comprise panoramic and projective distortions,earth rotation, attitude, altitude and spacecraft velocity variations. (Bernstein, 1976).

The most common methods for geometric correction of LANDSAT imagery make use of ground points (GCPs) and build a polynomial model which globally corrects the image. These methods, although simple, need a great number of well-located GCPs in order to perform well (Bahr, 1978); the alternative is to construct a model which makes use of collinearity equations when describing the relation between the image and the object coordinates. Such models need fewer GCPs in order to obtain the prescribed accuracy, and this fact is especially important for mapping applications in remote regions. The drawback of this approach is the reliance on the platform's attitude and ephemeris data, which is of good quality in LANDSATs 4 and 5, but is of poor quality in LANDSATs 1, 2 and 3. The refinement of the attitude data is the main use of GCPs in such a method, and it is clear that the unreliable attitude data need a fair amount of GCPs.

The method chosen for the system developed at INPE was the geometric (collinearity equations) one, based on the facilities available at the institute's image reception station and due to GCP location problems for many areas in Brazil. Future improvements will include the development of a physical attitude model in order to take into account the physics of the platform, such as the one developed by MDA (Friedman et al, 1983).

III - MODULE 0 - MANAGEMENT

The management module will present to the system's operator, at any moment of the processing, a complete view of all the tasks under request. This is possible because of a special file: the "status file" (STA). It contains every request made to the system not yet completed, and is the key to the access to all other files. For every request it relates all the necessary processing, indicating which steps have been completed. It also contains auxiliary information, such as the desired cartographic projection, bands to be utilized, mosaic information, and whether GCP are available for the scene. Other files built specially for the system are: image files containing original, corrected or mosaicked images; satellite parameter file containing the attitude data ("roll", "pitch", and "yaw"), as well as the coefficients for the polynomial series which describe the attitude's variation; correction parameters file which includes ellipsoid, mirror, and satellite specific data: and the break-point matrix file, which contains the deviations for a reseau which covers the corrected image, and is used in the resampling process.

IV - MODULE 1 - PLATFORM PARAMETERS DETERMINATION

The procedures in this module are concerned with the task of obtaining the position of the spacecraft as a function of time (ephemeris data) and the orientation of the spacecraft as a function of time (attitude data). The calculation of these data depends on whether the image was obtained by satellites LANDSAT 1, 2 and 3, or by LANDSAT 4 and 5.

In the case of LANDSAT 1, 2 and 3, a horizon detector measures the spacecraft's roll and pitch. This is the so called Attitude Measurement Sensor (AMS). The AMS is a static sensor which detects the infrared energy coming from the horizon, and the roll and pitch are estimated based on the measured differences in the along-track differences. These differences, expressed in counts, come in the satellite's telemetry data; then, a horizon infrared energy profile is used to calculate the roll and pitch values. The spacecraft yaw is not measured, and it is recommended by NASA that the following formula is used:

$$\text{yaw} = -1.15 \times \text{roll}. \qquad (1)$$

The accuracy of this AMS data, however, is about 1.0 milliradian, not sufficient to obtain a corrected image with a location correctness of 1 pixel. As for the data, experiments (Tsuchia and Yamarra, 1981) have shown that a linear formula such as (1) is not sufficient to obtain them with the average accuracy.

The ephemeris for LANDSAT 1, 2 and 3 is interpolated based on orbital elements furnished by NASA.

In the case of LANDSATs 4 and 5, a different system is used to obtain the platform's attitude data: it consists of a set of gyroscopes and a star sensor, and it has a much better performance than the AMS of the previous satellites. The telemetry data is composed of: a) Euler parameters providing the platform's attitude relative to an Earth-centered inertial referente system, given at each 4.096 seconds. b) Gyro readings given at each 0.512 seconds. This data will enable the calculation of the platform attitude on a subsecond basis. c) Cartesian coordinates giving the satellite position in an satellite-centered inertial reference system.

In the latter case, using the Euler parameters, the gyro drifts and the platform coordinates, the roll, pitch and yaw errors are calculated, and the satellite coordinates in an Earth--centered reference are obtained. Such results have an accuracy of at least one order of magnitude over the LANDSAT 1, 2 and 3 data.

The final result of this module is a file which contains, on a second by second basis, information about the satellite position and its derivatives, as well as attitude data. Because of accuracy problems of the horizon sensor of LANDSATs 1, 2 and 3, a refinement procedure that estimates such data with better performance is needed. Such a procedure uses ground control points and is described in the image geometry module.

V - MODULE 2 - CCT ACQUISITION

The procedure of this module are responsible for transfering the CCT-recorded image to the system image files, which reside on disk. The auxiliary data contained in the CCT are also copied for inclusion in the output CCT. The work carried out is always directed by a user's request containing a demand, which may be simply a single scene correction (in one or more bands) or a mosaic generation. In the latter case, two scenes are needed in the standard product case (1.0 by 1.5 degress in the UTM projection).

The input tapes are available in the format BIP2 (Band Interleaved by Pixel Pairs) generated by INPE's processing station. The desired bands are then copied to the disk to the image files, which are organized in a BSQ (Band Sequential) format: each band occupies one image file. After the loading process, the image is corrected for the "line-lenght" and sensor effects. The "line-lenght" effect appears because the LANDSAT's image line lenght varies for each sweep, and its correction is basically a one-dimensional interpolation process, fixing the lenght at a nominal value.

As for the sensor effects, there are different models to correct the radiometric difference observed in the images. The most common one is linear equalization: a fixed gain and offset are imposed on each sensor's sweep. (Kumar and Cavalcanti, 1977). More suphisticated methods use a probabilistic approach (Banon, 1983).

VI - MODULE 3 - GROUND CONTROL POINT LIBRARY

A groung control point is a physical feature detectable in a scene, whose location is known precisely (Bernstein, 1976). Typical GCPs are airports, highway intersections, land-water interfaces, geological features, and field patterns. Use of GCPs is of paramount important is geometric correction, since they provide absolute reference for refining the equations which describe imae geometry.

For a more organized and efficient correction processing, it is desired that the GCPs pertaining a given image be localized in an easy and rapid fashion. This is achieved by building a Ground Point Library, which contains for a given region GCPs arranged into records. Each record contains information about the point, as well as a chip which include it. The information comprehends GCP identification, latitude, longitude and altitude, origin and type, and a figure of merit to evaluate the point's performance. As for the chip, it is a 32 pixel by 32 line array around the point. GCP libraries have proven very useful in geometric correction applications (Niblack, 1981).

This module has a set of procedures which permits the creation, management, maintenance and visualization, divided into 4 submodules: a) entry and update; b) point recovery; c) exclusion; d) listing.

The entry and update submodule enables identification and insertion of GCPs for a given region into the library, and makes updating of existing GCPs possible. First, a number of tentative GCPs are identified by means of maps and transparencies; secondly, these points are localized in a digital reference image, using an approximate geometry model (based only on intrisic satellite data) for a rough localization and a manual operation on a screen for a precise determination of position; thirdly, a refined geometry model is constructed based on satellite data and the localized GCPs, and badly identified points are determined and deleted; fourthly, a suitability check is performed on the remaining points to select those easily distinguishable for the background, and to make automatic GCP location as precise as possible; finally, the selected GCPs are entered into the library, together with their descriptive data.

To refine the model, existing GCPs over the scene are used, and a better estimate for the attitude parameters is obtained. The two most common methods for this task are least-squares adjustment and stochastic filtering. In the least-squares case, a polynomial is adjusted to the GCP set, and the residue obtained at each point is used to detect badly located ones. In a second step, the "bad" points are omitted. This is a simple procedures, but it works well only when a great number of GCPs are available.

In the stochastic filtering case (Caron and Simon, 1975), a Kalman filter is used to update the initial estimation of the attitude time series. The components of the state vector are the 12 coefficients of the third-degree polynomial series described above. The sequential estimator needs fewer GCPs than the least-squares one (Rifman et al., 1979).

After the refinement process, a correction matrix which covers the output image is derived. Deviations are calculated for each element, depending on the output projection, scale and desired pixel size. This matrix is used in the next step, the resempling process.

VIII - DESCRIPTION FOR MODULE 5 - RESAMPLING

The resampling procedure carries out the actual correction for all the pixels of the output image. The elements of the output space are mapped into the input space, and their gray level is computed by means of interpolation. This procedure is very time-consuming and its implementation is optimized in terms of the hardware available.

The mapping of any point is achieved using a rectangular grid of points derived from the image geometry module: any point in the output space is located by bilinear interpolation of the deviations to be imposed to the surrounding four grid points. For the interpolation process, there are methods avaiable, including nearest-neighbor and cubic convolution. Nearest--neighbor is a function which simply finds the input image location closest to the mapped output location and assigns its gray level to the pixel. Cubic convolution uses the 16 nearest points to calculate the pixel's gray value.

For the algorithm itself, the input image has a standard 3240 pixels by 2352 lines size, and the output image will have a 4096 pixels by 4096 lines size, containing the input image on a fixed 9 degree orientation. Because of memory restrictions, the output image is processed by strips of 512 pixels.

IX - DESCRIPTION FOR MODULE 6 - MOSAICKING

The mosaicking module obtains the combination of two corrected images in a standard UTM grid, covering 1.5 x 1.0 degrees. Due to the fact that INPE is the Brazilian institution which receives LANDSAT data, the picture center time can be adjusted so that only two scences will be needed for the UTM mosaic.

Firstly, a histogram equalization is applied to the corrected scenes. A registration procedure is then applied in order to determine the overlap region between the images and a reference for the editing procedure. Editing consists in making a fit, determining for each line "cut points" which indicate when one image ends and the other begins. Such points are chosen in order to minimize rediometric differences between the two images (Milgram, 1975).

X - DESCRIPTION FOR MODULE 7 - OUTPUT CCT GENERATION

The procedures in this module are concerned with the generation of computer-compatible tapes (CCTs) containing the geometrically corrected image. The CCT format follows LANDSAT technical working group (LTWG) recommendations so that the output tape is in a superstructure format. This format permits the generation of images in a band sequential (BSQ) and in a band interleaved by lines (BIL) format. The CCT will contain a header with all the necessary information for extracting the data.

XI - FINAL CONSIDERATIONS

The system is being developed in FORTRAN 77, in a PDP 11/34 computer which runs under the RSX 11/M operating system. Peripherals include a COMTAL Vision One/20 image display system and 4 RM02 magnetic disks totalling 168 M bytes of storage. Some of the resampling code is being written in MACRO assembler language for better performance, and an array processor is expected to be integrated into the system in the next semester.

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The entry and update submodule has also procedures for supplemental GCP generation. These GCPs are obtained directly from the digital image for a better distribution of the set of points over the LANDSAT scene. Using the refined geometry model, noticeable features are inserted in the library.

The point recovery submodule is used when an image to be corrected is entered in the system and the existing GCPs for the scene need to be recovered, in order to determine the corrections to be applied to the original image. It uses automatic correlation methods to obtain the pair line-pixel which corresponds to a given GCP on the library.

The exclusion submodule enables a point or a set of points to be deleted from the library. The decision to exclude a point is made based on its figure of merit, which measure its performance after a number of uses. The listing submodule is useful for printout and report generation.

VII - MODULE 4 - IMAGE GEOMETRY EQUATIONS

The procedures in this module are concerned with the construction of the equations which relate the point in the image to the point on the groun using parameters that have real physical meaning. These parameters are the satellite's position (ephemeris data), the platform attitude (roll, pitch and yaw), and the reference ellipsoid, and the model is called a parametric one. The mathematical model used relates the satellite's view line (a line, pixel pair in the satellite--centered reference system) to the correspondent view line in an inertial reference system (collinearity equations). A complete discussion of the problem is given in Mikhail and Paderes (1983). The module operates in three steps: first based only in the satellite attitude data, a polynomial time series which describes roll, pitch and yaw variations within a scene is calculated, and the first approximation of the model is obtained; secondly, existing GCPs are used to refine this model, yielding a model which better fits the physical situation; thirdly, a correction matrix is computed, containing the deviations to be applied to a regular grid on the image ("break-points").

In the first step, the parameters defining the attitude are assumed to be functions of time, usually polynomials of the third degree. Based on the initial set of 12 parameters, the first version of the model is obtained, as follows: the orientation of the satellite-centered system relative to an inertial reference is obtained (collinearity equations); then, the intersection line with the ellipsoid is calculated (bringing the inertial reference system to the sensor coordinate system), making use of a series of rotations which take into account the attitude of the scanner coordinate system; after that, the inertial reference coordinates are transformed into the geogentric Greenwich coordinate system; finally, the point's latitude and longitude are obtained, and the coordinates in the desired projection are calculated.

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