IMAGE CORRECTION FOR DIGITAL MAPPING

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ABSTRACT

Digital base maps generated from various source imagery, such as satellite imagery, airborne data, and aerial photograph, are becoming very useful and efficient. Digital map can provide detailed topographic, land-use and land-cover information on earth. With the growing requirements of automatically correcting raw data and generating digital maps, the technique which can be used for that purpose is demanded.

This paper introduces a system containing a serial set of methods to correct satellite image or aerial data for mapping. The technique makes full use of georeference and sensor model information, such as ephemeris data, geometric model, and/or GPS/INS positioning information, to automatically register and orthorectify the raw image data. Through mosaicking process, a seamless mosaicking image or image tiles is produced. Semi-automatic and manual editing can be performed to produce a standard map to satisfy a Mapping branch requirement.

This paper will briefly describe the mapping system concept and application that forms a production mapping flow. It will address on the Image Correction methodology including automatic image to image registration with initial direct georeference and DEM; automatic GCP error detection and sensor model refinement; orthorectification; and seamless cutline selection and mosaicking.

The introduced image correction system is an automated system. It consists of multiple processing component functions in a scripting environment. The scripting work flow is highly customizable to deal with large data set. It is also capable of data accessing, retrieval and delivery to Enterprise database, i.e. Oracle 10G, or web via complementary subsystems.

PRE-PROCESSING DATA

The image import function automatically identifies the file structure of a stored set of raw image files and extracts/converts relevant information to a known format. A DEM can be obtained in various ways, for example it can be acquired directly from third party providers, or it can be generated by software with stereo image data sources.

The approximate georeferencing models are obtained from the ephemeris/orbital data for satellite images or from the GPS/INS data for aerial photographs. GCPs, which inherently contain both image and ground coordinates, are required to detect blunders, to control the model quality, and to refine the approximate model to achieve a high-precision georeferenced result. For the purpose of improving efficiency and for automating the procedure, we select and store a set of GCPs in a database structure. All the relevant information about a GCP and the neighboring pixels that surround the GCP are included as the structure data. This structured data is called a GCP chip, while the database is called the GCP chip database. The purpose of using a GCP chip database is to permanently store GCP chip information that can be easily accessed and reused with new images in an automated procedure. We have various options to create a chip database: manually extract in an interactive environment, automatically extract from orthorectified images, or from raw images with precise math models and corresponding elevation information.

AUTOMATICALLY REGISTERING RAW IMAGERY

The georeferencing model relies on two sets of data: camera/sensor information to set up the mapping equation, and GCPs to refine the parameters in the model. During the modeling stage, both forward and backward transformations between the raw pixel and line coordinates and the georeference coordinates can be established. The GCPs are used to refine the approximate model to achieve a precise georeferencing result and to detect blunders

In automating the procedure, the main problems we met with were geometric deformation and/or clouds on the raw image. Clouds on the image cause mismatching in the correlation step and also affect the radiometric balancing algorithms. The geometric deformation in some extreme cases is so serious that the pixel ground resolution at the edge of a raw image is almost two times that of the center, and the orientation for each pixel is dependent on its position in the image. To solve these issues, a special procedure was developed with two options. The first option is to directly register each raw image onto a georeferenced image that has been orthorectified in a previous processing case with possibly various resolution and common overlapping area. Depending on the approximate camera/sensor model and DEM, a roughly orthorectified image patch surrounding the estimated position on the raw image is generated on the fly, and a correlation processing is then applied between that patch and the projected template area on the georeferenced image. Each successful correspondence will be reported and collected as a new GCP point of that raw image. Furthermore, a set of these newly collected GCP points with relevant sub-ortho-image may be stored in the format of GCP chip database for repeat use in future. The usage of chip database in fact is our second option. In this second option, a newly generated or existing GCP chip database will be used as precise georeference base. Similarly, we orthorectify a sub-area from the raw image by using the initial georeferencing data, the elevation, and the pixel sampling distance (PSD) from the GCP chip structure to make both the sub-orthos and the chip images in the same reference surface and resolution. This process can greatly reduce the affects of geometric deformation. After this preparation, we are ready to perform the critical matching procedure to register each individual GCP chip onto the sub-ortho image, and project into the raw image. Assuming all the GCPs are located on edge corners, we set up the following hypothesis between the sub-ortho image and the chip image:

- They have same edge features and similar corner points.
- The GCP should be located on or very close to one of the extracted corner positions.
- There is the same number of intersected edge lines crossing the corresponding GCP point. And, those conjugate linear edge features have similar geometric and radiometric characterizations.
- Violation to any one of the matching criteria leads to an incorrect match and the candidate position should be filtered out from the matching list.
- Successfully passing all the matching criteria results in a correct position.

Some Detailed Steps

Edge detection. To locate each edge precisely, We firstly check and preprocess the raw image quality. If a raw image data contains noise and blurriness, a Gaussian smoothing is performed on the sub-area . Then the gradient in horizontal, vertical, and diagonal directions are calculated and stored for both edge detection and corner detection. In the edge detection step, weak edges (and also weak corners) always exist. To avoid skipping those features, we consider about all the four directional gradients and compare them with corresponding thresholds to decide each edge pixel. The output of the gradient edge detection is a binary edge image but it may contain wide ridges around the local maxima. The required final position of the edge lies approximately in the middle of this wider edge [3]. To extract the central position of the edge, a thinning (or skeleton) filter is applied. We have implemented the Kreifelts [4] algorithm to filter out non-skeleton pixels.

Corner detection Since a GCP is always located near a corner feature, we can capture corner structures in patterns of intensities [Trucco]. Using the gradient images, we immediately calculate the eigenvalues of a sum-gradient matrix C. Comparing the minimal of the two eigenvalues with a pre-defined threshold, we may decide the candidate corner position.

Azimuthal characterization matching is an algorithm that was first proposed by Motrena et al [6]. The approach is to solve the rotation-variant problem existing in area-based correlation method. It is based on the autocorrelation function of one azimuthal projection around a candidate GCP and has rotation and contrast invariances.

If an orientation variance (rotation) exists, the azimuthal projections of the sub-ortho image and the GCP chip image about the corresponding central pixels will differ by a phase factor: the sets are the same but the initial elements are different [6]. We may apply the autocorrelation function [6] to determine the rotation angle:

Linear Feature Extraction and Comparison

To improve the robustness, we add line comparison in the neibourhoods of the candidate point and of the GCP position in the chip. The Hough Transform line detection is performed in the thinned edge image surrounding those two positions. Usually there is two to four line sections in each patch that can be found. We can directly compare their slopes and/or the lengths and the brightness between the conjugate features to filter out mismatching.

Pyramid Cross-Correlation

Based on the rotation angle and the initial camera/sensor model, we may need to re-calculate the resampling to generate the sub-ortho image for each GCP chip, then perform coarse correlation and fine correlation in a hierarchical match process. The matched position is back projected onto the raw image. Figure 1 shows orthorectified image patches and a GCP chip.

Figure1a.
Sub-ortho image with a rotation error

Figure 1b.
Sub-ortho image after removing rotation error

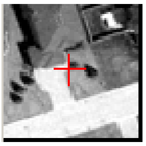

Figure 1c.
GCP chip sub-ortho image

RECOVERING AND REFINING SENSOR MODEL

The mathematical model relies on two sets of data: orbit/sensor information to set up the mapping equation, and ground control points to refine the parameters in the model.

The structure of the math model varies with the different sensors. The sensor models define the mapping between raw image coordinates and a reference coordinate frame of the sensor, together with the imaging time. The orbital model encapsulates all knowledge about the characteristics of the satellite position and attitude in its orbit, over the image of interest. The model corrected or constructed with the ground control points forms the basis of precision mapping.

GENERATING ORTHO AND MOSAIC

With an accurate georeferencing model for each image and a Digital Elevation Model for the working area, we can generate orthorectified images. Because of the existence of inconsistent radiometry, we may perform hot spot removal and radiometric balancing on the orthorectified images, and then merge them into an image map.

Hot spots can be described or represented as a 3D ellipsoid located on an image. The third dimension represents the intensity variance. The parameters of this model can be calculated through a least squares algorithm. Using the obtained parameters we can reduce or eliminate the hot spot effect. When inconsistent radiometry exists between images, we have to apply radiometric balancing. A global bundle calculation is performed based on overlapped areas to figure out a set of correction parameters or lookup table for each image. Cutline selection is one of the most important steps. An optimization model for computing cutlines can be set up, which includes a cost function of a criteria and a set of constraints. We use optimal programming to solve the model and get polygon shaped cutlines for each ortho image. Pixels inside the cutline will contribute to the final mosaic image.

ACCESSING AND STORING DATA

The objective of the set of steps is to build a fully automatic image correction system. We are targeting on processing large data set for enterprise level usage. Beside the correctness of the algorithms, the critical consideration includes efficiency of data accessing and storage capability. In our system, Oracle 10G has been used as the central data storage and all the raw, intermediate and final results of the procedure are stored in the Oracle database and accessed through PCI vs Oracle interface engine.

IMPLEMENTATION

We have developed an automatic image correction and mapping system in a Python PPF (PCI Pluggable Functions) scripting environment. This is a fully automatic processing system with Python script batch processing environment supported by PCI Dynamically Linked Library (DLL). One study area is in Canada. The satellite images are 15 m Pan-chromatic (PAN) and 30 m Multi-Spectral (MS) color imagery covering the whole country, which contains more than 700 landsat image scenes. A Chip database contained 50k of various resolution image chips in this areas has been used as the georefrence base. DEMs are 90 m USGS DEM.

After automatically collecting GCPs, a rigorous sensor model was constructed for each image scene. The images were then orthorectified and a Pan Sharpening process was performed to fuse the multi-spectral and panchromatic imagery to obtain Pan-Sharpened orthorectified images. Finally, we mosaicked the orthorectified images into a large raster mosaic map, with hot spot removal and histogram color balancing processing. Figure 2 shows the mosaic, which consists of four Pan-sharpened images. Figure 3 shows the mosaic generated from over seven hundreds of panchromatic scenes. In this testing data set, the images were taken from various seasons in different years. So the brightness matching in the mosaic is not perfect. Also, there are a couple gaps/holes left in mosaic because of the lack of some scene data. This example is to show the concept of our automatic procedure and some tests on the system. To obtain map-quality mosaicking result, a good quality of raw images with consistent radiometric characteristics, i.e. taken within a short period of time, is highly recommended. A research direction is to construct a parameter configuration matrix on each processing component function based on various input/output data and their configuration parameters.

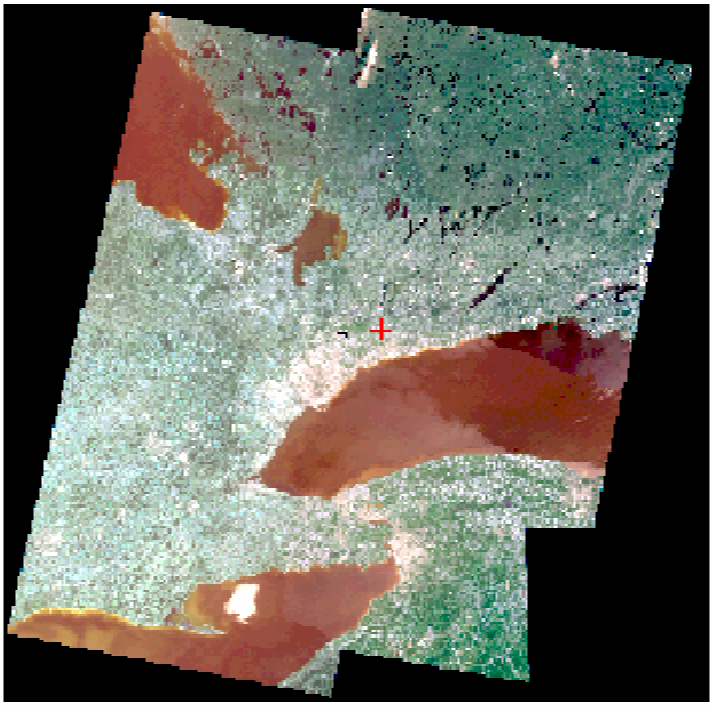

Figure 2. Mosaic of four scenes.

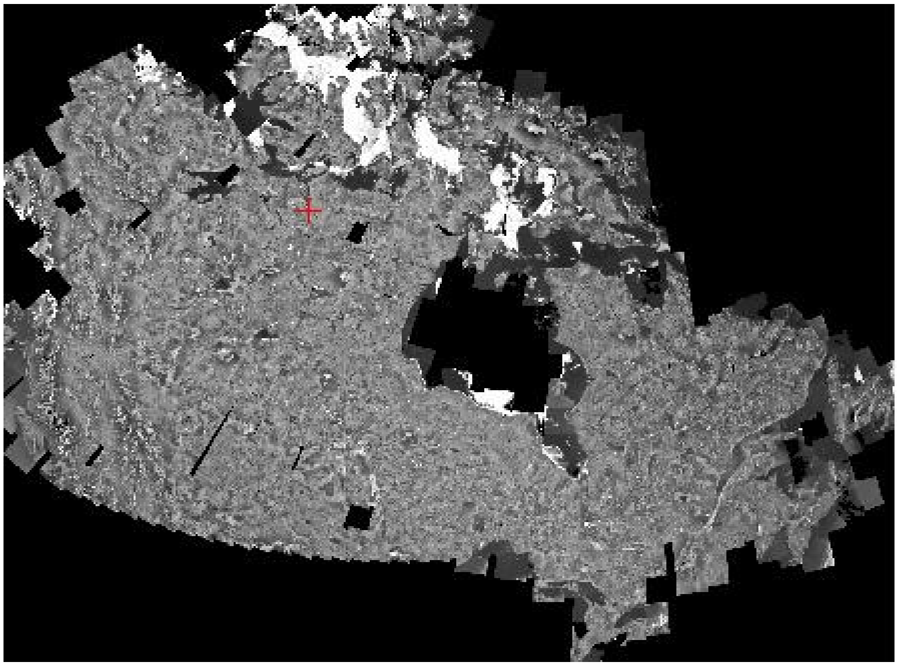

Figure 3. Mosaic of whole Canada with panchromatic images taken in different seasons.

CONCLUSION

The automatic procedure described above has been developed and implemented in PCI's ProPack software product. The experiment shows very positive result in terms of efficiency, reliability and accuracy. Through the development, implementation, and analysis of the results, the following conclusions are made:

- The presented automatic procedure is implemented for fast, accurate, efficient and reliable image map generation, in a Python environment.
- Oracle 10G is a powerful data storing and accessing system in handling raster, vector, and attribute types of data through PCI-Oracle interface software.
- The technique has been successfully applied on various types of imagery.
- The system is able to process a large data set fully automatically.
- The procedure produces high quality image maps with good image source.
- Although the whole procedure is highly automatic, some options and interaction are still required to guarantee the product quality.

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