Automating Image Map Generation Using Satellite Images and Aerial Photos

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Abstract

Image maps generated using satellite images and aerial photos are extremely useful. The map can provide detailed topographic, land-use and land-cover information on earth. With the growing number of satellite and aerial photo data, a technique which can generate/update maps automatically from satellite images and aerial photos is necessary.
This paper presents a technique developed at PCI Geomatics which can generate/update maps automatically using satellite image or aerial photo data. The technique uses the ephemeris data and a geometric model for satellite data, and GPS/INS data together with the collinearity equations for aerial photos. In addition, a chip database containing a set of Ground Control Points (GCPs) image chips was used to collect GCPs automatically.
To generate GCPs, a hierarchical multi-level correlation procedure was applied to match image chip stored inside an image database with raw images. This matching process includes the popularly used algorithms: sub-image pyramid, geo-transformation, resampling, correlation and least square matching. The automatically generated GCPs are then passed through a statistical filter to remove blunders, i.e., mismatched chips. Using the resulting GCPs, a refined, precise and reliable geometric model can then be obtained to generate the orthorectified images. An automatic mosaicking process, which can search the optimal cutlines, perform colour balancing and hot spot removal, was then used to generate a seamless mosaic.
All the described processes and features in this paper have been fully integrated and implemented into some PCI software products, such as OrthoEngine and Geocomp-n systems.

Introduction

Digital satellite imagery and aerial photograph have been used to acquire the most up-to-date information about the earth's surface. Various resolutions of images, from 1km AVHRR (Advanced Very High Resolution Radiometer) data to 15cm aerial photo, have been popularly used to generate softcopy/hardcopy image maps for monitoring the seasonal variations of forest, agricultural and grassland vegetation conditions (Eidenshink, 1992), planning land use and constructions and so on. Applications include composite different image patches from daily orbital passes to make one nearly cloud-free image for that individual period, to mosaic a large number of raw images into a consistant ortho-rectified digital map through a semi/fully automatic procedure. For this purpose, a very precise orbit pass model for satellite images or exterior orientation model for aerial photos, referenced to a specified geo-referencing system, is required for each image. This has been implemented as the geocoding section in the whole system.

Mosaic cutlines for each image is then automatically selected based on some pre-defined criteria.

This paper introduces the geocoding sub-system, quality assurance and quality control, and ortho/mosaicking image generation. The system consists of following parts:

- Construct the satellite, sensor, and earth models, using all available a priori information from the downlink, as well as both pre and post launch calibrations (Xin *et al.* 1998), or directly use INS/GPS data for aerial photos.
- Generate a GCP chip database that contains the complete information for a set of GCPs (including geo-coordinate, image chip, resolution, etc.). This step can be achieved by using the PCI software ChipManager, or can be generated by following PCI's data structure.
- Perform a series of geo-transformation, hierarchical cross-correlation and least squares matching, in order to register a set of GCPs from the chip database onto the raw images. The models mentioned above are then refined, by using the matched result.
- Apply statistic test and simultaneous triangulation to check data and the obtained models.
- Create each ortho image using the georeference model and generate mosaic cutlines.
- Perform hot spot removal and radiometric balancing, and build a seamless mosaicking image.
- Edit the mosaic to produce a standard image map.

In order to georeference a raw satellite image, we have to consider the sensor, orbit, and earth models. For each image, a various number of successfully matched GCPs are required to fulfill model calculations depending on sensor types. The GCP chip may be extracted from various geocoded images that are in consistent pixel resolution and attached with all the necessary information. It is difficult to automatically identify GCPs on raw images with high reliability, because images are mostly geometrically distorted, cloudy, which obscures GCPs or causes mismatching. When georeference model for each image is obtained, a polygon shaped cutline of that image can be decided using optimizing algorithms. In this processing, radiometric distortion can also be filtered out or reduced. Finally, an image map in standard map format is produced using our cartographic software.

In this paper, we will discuss a procedure that matches a GCP chip onto the raw image, checks the quality and refine georeference models using the automatically collected GCPs and tie points (TPs), and create cutlines to produce an image map.

Model Construction

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. For satellite imagery, it represents a complex function of many parameters and may consists of multiple layers of modeling: a sensor model; an orbit model representing the position and attitude of the satellites as a function of time; an earth model representing the shape (or assumed shape) of the earth, including any terrain effects. As for aerial photos, it represents the exterior orientation parameters plus the collinearity equations.

The structure of math model varies upon the different sensors. For example, AVHRR image model can be represented with four models: sensor model, orbit model, earth model, and map model. Sensor Model defines the mapping between raw image coordinates and a reference coordinate frame of the sensor (or satellite), together with the imaging time. The mapping can be set up from the geometric and timing characteristics of the sensor. The Orbit Model encapsulates all knowledge about the characteristics of the satellite position and attitude in its orbit, over the image of interest. In particular, for the case of NOAA, when parameterized by a set of TBUS orbital elements, the orbit model is able to derive a systematic estimate of the position of the satellite at any time throughout the imaging window. With the help of ground control points, the timestate variables will be updated using dynamic filtering. The orbit model corrected with the ground control points forms the basis of precision mapping. The Earth Model provides a mapping between the sensor/satellite viewing state (direction and timing) and the geographic coordinates on the surface of the earth. The other one we may also consider is Map Model, which is used to describe the relationship between geodetic coordinates and map coordinates, but requirement of this model depends on the type of map projection.

The other satellite model and aerial photograph model are much simpler than the above AVHRR model and may only have one or two sub model layers. Through these stages of modeling, both forward and backward mappings between the raw pixel and line coordinates and the georeference coordinates can be established.

GCP Chip Database Generation

We can obtain the approximate georeferencing models for satellite images (ephemeris/orbit data) and for aerial photos (GPS/INS data). A set of GCPs that contain both image and ground coordinates is required to detect blunder, to control model quality, and to refine the approximate model to achieve a high-precision georeferencing result. The traditional method is to identify the similar object from a portion of a geocoded image and from a raw image. A GCP is usually selected on an obvious feature/object manually (this step is very time consuming).

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 necessary information about a GCP and the neighboring pixels that surround the GCP are included as the structure data. This structure data is called the 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 and then to reuse this information for each new image in the automating procedure.

The structure of GCP chip database data can be divided into three levels: File header; Chip pointer; Chip header. File header contains an overview of information about the database, such as total number of chips, generating time and version tag. Chip pointer contains a chip identifier, ground coordinates of the chip, map projection type, pixel resolutions of the chip image, viewing angle of the satellite and wavelength range of each channel. Most of the information about this chip can be quickly queried from this level, which allows the user to efficiently locate a specified type of chip. Chip header contains more information about the chip image, such as: chip image size, pixel location of the GCP, rotation angle of chip image for north up, the location of the chip image data in the database file and statistical results from GCP chip matching, followed by the chip image data.

An advantage of creating a GCP chip database is that each individual chip may be extracted from different source images containing various resolutions, map projections, sensor types and size dimensions. After the extraction, the source images will not be required in the subsequent steps.

Quality Control and Model Refinement

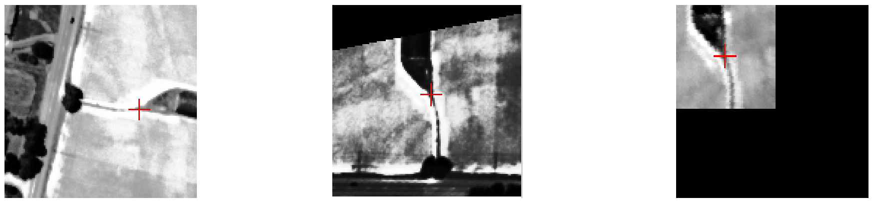
In remote sensing and digital photogrammetry, one of the most time-consuming tasks is imagery geo-referencing. As indicated in the introduction, the method we have implemented in order to resolve this issue, takes the orbital parameters or GPS/INS result into account and uses a small number of GCPs plus some TPs to check and refine geo-referencing accuracy.

In this stage, the critical step is the automatic identification of GCPs on the raw image. This step is difficult because the characteristics of illumination, viewing, orientation and resolution may be very different between the GCP chip image and the corresponding raw image patch. In addition, some serious geometric deformation may exist in raw images.

Existing approaches to the automatic identification of GCPs are based on structural methods. These types of algorithms used to identify features are much too dependent on the context, making them very sensitive to deformations (Motrena *et al*. 1998). The azimuth projection algorithm, introduced by P. Motrena *et al*., may improve the reliability, but it is still a type of feature-based algorithm which depends on strong features nearby and may not solve the issue, since it may contain serious geometric deformations. Through this study, we have found that an area-based cross correlation technique is still a powerful and reliable tool in automatic GCP identification.

In the processing, 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 radiometry in some areas. The geometric deformation 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 series of resampling and hirarchical matching processing steps are performed.

- Because of geometric deformation, matching can not be performed between the raw image and the chip image directly. We generate a sub-ortho image from the raw image for each chip within the image boundary, then match this image with the chip image. The Figure 1 show an example of matched image case: (a) interest sub-area on raw image, (b) sub-ortho image and (c) chip image.



(a) Raw image (b) Rectified image (c) Chip image

Figure 1

- Following are the hierarchical correlation steps. The background image and chip image will be down-sampled up to one or two levels (depends on chip image size). A patch of the image surrounding the GCP pixel location is used as a master image and is used to correlate throughout the down-sampled background image. Choose the pixel with the highest correlation score on the background image as a matching point and pass it to the next lower-level correlation stage. When a matching point is obtained on a full resolution image, a smaller mask size is used to refine the result. Finally, a least squares matching is performed to achieve sub-pixel accuracy. We may also perform this matching method for tie point collection. The obtained TPs strengthen the connection between images inside a block so that it increases geometric redundency.
- After successfully matching a set of GCPs on a raw image, we may re-calculate to check or refine the orbital model, using those geo-registered GCPs and TPs. A statistical test is applied to detect and skip those with larger residual errors (possibly with blunders). The model is repeatedly calculated and the final result with lowest RMS is chosen.

Ortho Mosaic Generation

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

Hot spot can be described as a 3D ellipsoid located on an image. The third dimension represents the intensity variance. The parameters of this model can be calculated through least squares algorithm. Using the obtained parameters we can greatly eliminate or reduce the hot spot effect. When the inconsistent radiometry exists between images, we have to apply radio 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 the most important step. An optimization model for computing cutline 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 cutline will contribute to the final mosaic image. Figure 2 shows the automatically selected cutline on an image.

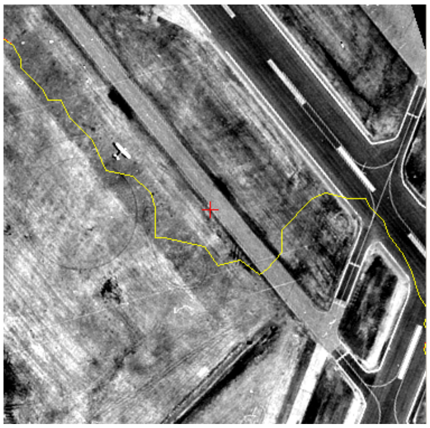


Figure 2 Cutline on an image

In practice, the above processing steps can be applied on fly. We get parameters or models from each step and process/filter each pixel through those parameters/models to directly generate the mosaic image from the raw images in a fully automatically procedure. Using editing software, we can produce the final image map.

Conclusion

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

- The presented automating procedure is implemented for fast, accurate, efficient and reliable image map generation, in a user-friendly desktop environment.
- The technique has been successfully applied on various types of imagery.
- The hierarchical correlation may effectively reduce the amount of mismatching.
- The automatic mosaicking procedure is very efficient to generate high quality image map.
- Although the whole procedure is highly automatic, some interaction is still required to guarantee the product quality.

References

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