DEM OPTIMIZATION USING SATELLITE IMAGES

Massoud Sharif

International Institute for Aerospace Survey and Earth Sciences (ITC)
P.O. Box 6, 7500 AA Enschede, The Netherlands
Tel. +31-53-4874345, Fax. +31-53-4874335
E-mail: SHARIF@ITC.NL

Mehrdad Jafari Salim
National Cartographic Centre of Iran

Commission IV, Working Group 4

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ABSTRACT

An important use of satellite data is the production of image maps. Today, production of digital ortho images has become more operational due to the development of more powerful computers with sufficient resources, easier acquisition of input data, increased generation of digital data, development of many commercial ortho image production systems, and new application areas, particularly in connection with GIS and digital mapping.

The purpose of the research work was to analyze the capability and possibility of applying the automatic DTM generation methods from stereopairs of SPOT imagery intended for 1:50 000 scale image maps. The experiment was an automatic DEM generation, performed on a stereopair of SPOT imagery (panchromatic, level 1A) covering a hilly area geographically located in the Aix-en-Provence region in the south of France. SPOT panchromatic stereopair (level 1A) supplemented with morphologic lies provide the primary information. The processing is applied to an image dataset of 20000*10000 elements 200 km^2 on the ground. The 10*10 m grid automatic DEM is generated, and used to correct the image data. The 20 m interval manual height measurement on TRASTER T10 along three different lines within the area is accomplished to obtain three different profiles, to evaluate the systematic error on automatic generated DEM. The 10 m interval contour lines of the 1:25,000 scale topoplot produced a Digital Elevation Model, which is used to evaluate the relative accuracy of automatic generated DEM.

INTRODUCTION

The increasing demand of the map for planning and development on one hand, and limited application of obsolete maps because of continuous changes of the topography of the Earth, on the other hand are putting pressure for faster and more economical map making. As the analogue techniques for topographic mapping and map updating are time consuming, labour intensive and expensive, the photogrammetric and cartographic communities are roused to explore faster and operational techniques for topographic mapping.

Remote sensing data from space seem to bring a potential solution for this problem, specially with the significant improvement in spatial and resolution of spaceborne imagery.

However, a more important and successful use of satellite data is the production of image maps. Image maps based on digital ortho images provide great advantages in comparison to their analogue counterparts, especially with respect to the flexibility, production of derived products and combination with other datasets.

1. EXTRACTION OF INFORMATION FROM SATELLITE DATA

A variety of different production processes for extracting thematic information about the Earth's surface from satellite data are present. Two general methods, namely visual image interpretation and computer-assisted image analysis, that can support topographic mapping are outlined. These methods can be applied at different levels. Regardless of the level or combination of methods employed, there is almost always a requirements for effective man-machine interaction. Furthermore, the quantity and quality of thematic information that can be extracted from satellite data increases when combinations of various types of satellite data are used and when the satellite data are combined with other types of graphic and tabular data [Nyquist, 1987; Lauer, 1986].

2. COMBINATION OF SATELLITE INFORMATION WITH CONVENTIONAL SOURCES

Satellite-derived data rarely provide all information sought and, in any case, in order to be useable, they need to be combined with minimum of topographical or thematic reference elements to make it readable and be able to analyze the contents of the "space-map".

Considering the two families of maps, where satellite imagery plays a role, i.e. general (or topographic) maps and thematic maps, different problems and specific methods are detected for combining the available information. In order to consider these methods, depending on the problems that arise, the following aspects will be discussed:

Geometric adjustment of the satellite information and conventional information, Assembly and cutting of the image along the map edges, Radiometric processing of the image to form the map background, Adding the conventional information to the satellite data

2.1 Image map production

The production of image map has three major parts (table 2.1):

Table 2.1 Production line steps in Image mapping

Input	Processing	Output
Digital Imagery	Geometric correction	General image maps
Digital Elevation Model (DEM)	Radiometric correction	Thematic (classified) image maps
Image orientation parameters	Mosaicking	Thematic image maps

2.2 Geometric corrections

Geometric corrections *concerns operations such as Geometrical preprocessing, Geometrical processing, Geodetic referencing (considering GPCs, and GPS measurements), Establishing transformation model (Polynomials, others), Resampling*

2.3 Radiometric correction

Radiometric correction concerns *Radiometric preprocessing, Defective pixels and lines replacement, Destriping, Clouds substitution, Haze correction, Noise smoothing, Slope correction,*

Radiometric Enhancement (Contrast enhancement, Colour enhancement, Edge enhancement)

2.4 Quality control of Image maps

With respect to the process involved in satellite image mapping, it will be easily understood that three elements are effecting the overall quality of final result: firstly the quality of input data such as image (Discussed on chapters 2 and 7), Digital Elevation Model and ground control points(discussed in chapter 6), secondly the method, equipment and finally operator skill and care applied during the processes such as rectification, mosaicking, screening, reproduction, etc.. Apparently, reaching high quality satellite image maps is impossible unless all elements

3. DIGITAL ELEVATION MEDEL, GENERATION AND ASSESSMENT

A Digital Elevation Model (DEM) is an ordered array of numbers that represents the spatial distribution of terrain characteristics. Different methods of data acquisition for DTM is rewied, namely; sampling (selective, progressive, composite, automatic) DTM from aerial photography, more attention is paid to automatic DTM generation using image correlation or image maching techniques.

3.1 DEM data structure

DEM is used to present the terrain in the form of surfaces that can, mathematically or numerically, be defined. They are broadly classified into models which are based on structuring the points into some specific order, taking into account their spatial relationships, and models which are based on fitting mathematical functions into the elevation data [Ackermann, 1978].

DEM is classified into the grid structure (regular, semiregular, irregular), TIN data structure, surface patch quadtree, mathematical representation (polynomials, others).

3.2 DEM generation

A DEM system consist of 3 basic components: Data acquisition, processing (pre, main, post processing), storage and retrival. the method of data acquisition is adapted to specification of output, constraints and terrain characteristics.

3.2.1 Data acquisition.

Data acquisition can be performed directly or indirectly. Indirect (photogrammetric) data acquisition concerns sampling (selective, prograssive, composite) [Makarovic, 1976], image matching (correlation) technics.

3.3 Image Matching Concepts

One of the most significant applications of image matching is modelling of the terrain relief (automated DEM generation). Automatic measurement of the parallaxes in stereo images (image disparities) by software, is in fact, the essential base of this method. Because the amount of image information involved is huge, the process has to be time efficient. Moreover, to attain sufficient quality, the accuracy and reliability of image matching are of dominant significance.

The principle behind image matching and height determination relies on a matching points being found in two images. A mathematical relationship exists between the parallax, distance between matching points in the images due to the different view positions, and the height of the actual terrain at the matched position.

3.3.1 Characteristics of satellite imagery influencing automatic height determination (case of SPOT)

The first stage in image processing is therefore to improve the information on satellite position and view direction.

Processing aerial photographs relies on a property known as epipolarity. This means that, after suitable rotation of one of the photographs to bring them into alignment, it is possible to scan along a line in the one photograph and find matching points along a matching line in the other.

This property is important in computer processing, because it enables a scan-line in one image to be related to a scan-line in the other, and match points are found with a one-dimensional search, among pixel values that are adjoining in memory.

SPOT images do not have this property, because the scan-line are imaged at different times from different positions, and because of the Earth's rotation. It is often desirable to preprocess the images in an attempt to enable epipolar scanning. A resampling scheme based on estimated satellite position can be performed to simplify the later step of finding matching points in the images.

In order to bring the SPOT images into epipolarity condition and also enabling extraction of metric information from images, a mathematical model is used to represent the platform/sensor imaging characteristics and other influencing parameters like Earth'rotation and earth's curvature.

Almost all authors use the collinearity condition equations developed for aerial photogrammetry as the basis for their algorithm to evaluate point heights [Carrol, 1987; Priebbenow, 1989; Koency et al, 1987; Westin, 1990]. The image coordinate systems need to be rotated and translated according to the ground coordinate system.

In addition to the pixel location on image and the object point coordinates, the collinearity equation usually contains six elements of exterior orientation. It is important to notice that theoretically due to the continuous movement of platform, for each pixel there should be six different elements. However for the relatively short period of scanning one line of imagery, it is common to consider only one set of six elements for each line.

The collinearity equation corresponding to one line is:

$$A_{image} = \lambda \, M \, P_{ground}$$

Where, A_{image} is the coordinates of an image point in the image coordinate points; P_{ground} is the coordinates of the object point in the ground coordinate system; λ is a scale factor, the ratio of distance between image points to the distance between corresponding object points; and M is an orthogonal three dimensional rotation matrix, allowing the image plane to be rotated parallel to a ground system.

The orientation of one image of the SPOT satellite is defined by the coordinates of the satellite position X_s; Y_s; Z_s and its orientation angles ω_0, Φ_0, and χ_0. Because of the movement and nonuniform gravity of the earth the satellite does not move in a simply defined orbit, and the coordinates of position and the orientation angles are function of the time. Figure 4 shows the effects of these variations [Koency et al, 1987].

The most direct method for functionally expressing the exterior orientation elements for satellite based sensors is to model the vehicle motion by orbit parameters. The satellite position as well as its nominal heading can be calculated as function of time, and then in the collinearity equation while the rotational elements (ω, Φ, χ) of exterior orientation appear, the positional elements are now replaced by functions of the orbital parameters.

The stereo pairs of SPOT images are taken at different times (often within five days), so because of transitory phenomena such as cloud, haze, etc, patterns will not always match up between two images. Because images are slowly sampled over a nine-second period and form different rotation angles they are non-epipolar. Day & Muller (1989) indicate that rotation and translation can render the images near-epipolar, but that in practice it is not possible to resample to true epipolarity without iterative adjustment. Hence mathematical models that do not require true epipolar geometry are preferred.

3.2 Algorirhm for matching

There are two basic approaches to finding matching points in the two images. The first of these is the area-based, or correlation method, and the second approach is feature-based.

3.2.1 Area-based algorithm for matching points

In this method the pixel data is compared directly, searching for the position in one image corresponding to target point in the other. The measure used to determine the match is based on a correlation coefficient calculated over a small area.

3.2.2 Feature based matching algorithm for matching points

In this method the original pixel data is simplified, retaining only points or lines of major intensity change which will correspond to some `features' of the landscape. Matching then usually assumes epipolar geometry, that is for a line of pixels in one image, a line of pixels can be found in the other image that is collinear with it. This greatly simplifies the matching process, reducing it to one-dimensional search. Epipolar geometry is generally possible with aerial photography, but is difficult to achieve accurately with satellite imagery because each image is built up over a nine-second period, scan-line at a time. During this period, the satellite moves a considerable distance, and the earth rotates. This means that, strictly, one image can not simply be rotated to gain epipolarity.

Feature-based matching could be based on matching point features or edge features. With the point-based approach distinct points (interest points) are obtained from each image and matched. In contrast, edge-based solution identifies distinct edge from each image using an edge detector (Otto & Chau, 1989). Edge detectors are mathematical operators, operating on different directions.

4. EXPERIMENTAL TEST

The purpose of the practical work was to test the state of the art of the digital image mapping model discussed before, and it meant to analyze the capability and possibility of applying the automatic DTM generation methods from stereopairs of SPOT imagery intended for 1:50 000 scale image maps.The experiment was an automatic DEM generation, performed on a stereopair of SPOT imagery (panchromatic, level 1A) covering a hilly area geographically located in the Aix-en-Provence region in the south of France.

Due to some limitations caused by imperfection of devices and lack of accurate knowledge about parameters involved in automatic DEM generation function it is still doubtful whether this method will satisfy all necessary height information specifications required for image mapping at scale 1:50,000.

However, regarding the scale of the image map e.g. 1:50,000 and a contour interval of about 10 to 20 m (for arid area), it can be concluded that the final image map must have the planimetric accuracy about 10 to 15 m (i.e. (0.2 to 0.3)*50,000/1000= 10 to 15 m) and altimetric accuracy (contours) about 3 to 7 m (i.e. 0.3 * (10 to 20) = 3 to 7 m). Therefore, the question to be answered is " Does the automatic DEM generation method provide height information, accurate enough for both, differential rectification of image, reaching to the 10 to 15 m planimetric accuracy, and also contour line generation. To answer this question the SPOT panchromatic stereopair (level 1A) and the infomap 3142 at scale 1:25,000 provide the primary information. The processing is applied to an image dataset of 20000*10000 elements 200 km^2 on the ground. The 10*10 m grid automatic DEM is generated, and will be used to correct the image data, and be compared with DEM generated from contours.

The 20 m interval manual height measurement on TRASTER T10 analogue stereo plotter along three different lines within the area should be accomplished to obtain three different profiles. This is done to find out the systematic error on automatic generated DEM. The 10 m interval contour lines of the 1:25,000 scale topoplot will be digitized to produce Digital Elevation Model. The DEM will be used: to evaluate the relative accuracy of automatic generated DEM.

4.1 Quality assessment of DEM generated automatically

The purpose of this section first is to evaluate the quality of automatic generated DEM by analysis of statistical result of residuals among two DEM, Automatic one and reference DEM which has been generated by digitizing contours. The second purpose is to evaluate the planimetric differences between two orthoimages rectified from left and right stereopair with automatic generated DEM. In fact, There should be no planimetric differences between same objects being found in two orthoimages from left and right, if the DEM applied in rectification had been accurate enough.

4.2 Altimetric accuracy evaluation

To evaluate the two DEM, 1500 points along three different lines with interval 20 meters had been selected and the differences in height between corresponding points in each line were calculated.

Subsequently, the results of this computation are as follows:

Statistical result of comparing 3 profile on both DEM		
	Mean value of residuals	Standard deviation of the residuals
Profile 1	6.5	8.5 m
profile 2	8.2	8.7 m
Profile 3	3.2	10.2 m

Table 8.2 Statistical results of differences on three profile derived from DEM generated automatically and DEM generated from digitizing contours

According to (Imhof, 1982) , it is obvious that the all differences have same direction therefore a systematic error exists. To find out the sources of this systematic errors. It was decided to measure the same profile by manual method with TRASTER T10 just by putting the floating mark on the ground on the same points that we had the height from two existed DEM, and then compute the statistical results for profiles driven from contours and from manual method.

Subsequently, the results of this computation are as follows:

Statistical result of comparing 3 profile		
	Mean value of residuals	Standard deviation of the residuals
Profile 1	3.02 m	8.8 m
Profile 2	-0.35 m	9.04 m
Profile 3	-0.60 m	8.3 m

Table 4.2 Statistical results of differences on three profile measured directly on stereo plotter and Three derived from DEM generated from digitizing contours

This result shows that, there is a systematic error about 8 meters, which actually is the tree height. It can be seen that in north part of the model the systematic errors are reduced (since the density of trees is reduced), but the random errors are increased, due to land cover patterns.

4.3 Evaluation of rectification via automatic generated DEM

Both left and right images from the study area have been rectified using automatic generated DEM in TRASTER T10 with module ORTHO-IMAGE then both were exported to ILWIS and 100 points have been measured in both of ortho images.
The standard deviation of the differences in coordinates is about 11 m. Regarding the resolution of the images (10 m) reveals that this DEM are reliable for image rectification (See figure 4.8). With regard to the figure 4.8 it is obvious that in the north and north west the amount of errors is increased with respect to other parts of the figure and this is due to the complex pattern of the area. In fact this method has got some problems in the area with no distinct ground objects and also may have large blunders due to the patterns of the ground. Therefore by examining the figure it can be seen that on that particular area image correlation for determination of height may become confuse.

5. Conclusion and Recommendations

We have reviewed the earliest work in matching stereo-images based on the idea of finding a matching patch, using a correlation function, or finding matching feature in two images. Area correlation has been found to be slow, but capable of sub-pixel accuracy. Feature matching is faster, but usually does not give sub-pixel accuracy. In feature-based as it has been mentioned, the integrity of method are based on distinct objects, therefore in area which is empty of distinct certainly it cause severe blunders and this method is not suitable to use.

Early work on automatic DEM generation was based on aerial photographs, which could be rotated with relative ease to use epipolar processing scan lines, but satellite imagery, captured over an extended processing time during which both the satellite and the Earth are moving, present geometric problems to be overcome at the same time as the matching process.

Image maps based on digital ortho images provide great advantages in comparison to their analogue counterparts, especially with respect to the flexibility, easy of use and understanding, production of derived products and combination with other datasets: containing more details, intended to wide range of users, produced by computer, able to be applied in GIS.

Tests performed at ITC have shown that a SPOT stereomodel, controlled by about 10 evenly distributed ground control points and rectified using an automatically generated DEM ensures sufficient planimetric precision for image mapping at scale 1:50,000. But the automatic generated DEM does not provide enough precision and fidelity to topographic features for contouring with 10 to 20 m interval. The remedial action was to supplement the DEM with morphologic information.

Quality control of image maps with respect to the process involved is actually the controlling of the three effecting elements on the overall quality of final result: firstly the quality of input data such as image, digital elevation model and ground control points, and secondly the method, equipment and finally operator skill and care applied during the processes such as rectification, mosaicking, screening etc.. Apparently reaching high quality orthophoto is impossible unless all these elements are established.

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