

USEFULNESS OF AUTOMATICALLY GENERATED HEIGHT INFORMATION
FOR TOPOGRAPHIC MAPPING AND LAND INFORMATION PURPOSES
- WITH EMPHASIS ON DATA EXTRACTED FROM SPOT -

Dan G Rosenholm
Swedish Space Corporation
P.O Box 4207, S-171 04 Solna, Sweden
Commission IV

Abstract

The operational system for computation of digital elevation models, developed and used by the Swedish Space Corporation, is presented. The products are described. Quality aspects of the computed digital elevation models, of the simultaneously computed orthophotos, and of the products herefrom derived is paid special attention. Results show that SPOT images and heights computed from SPOT stereo are well suited for topographic mapping in scales between 1:50 000 and 1:250 000, with intervals of the height contours between 10 to 50 meters. Examples of orthophoto maps (including height contours) automatically generated from SPOT images are shown.

Introduction

Aerial photography is a well-established remote sensing technique used throughout the world in mapping, land-use inventory and planning. Since the beginning of the 1970's, when the first Landsat satellite was launched, satellite images have also been used, as a less expensive and more easily accessible, alternative to aerial photographs. The main fields of application have been for minor projects in natural resources inventory and for prospecting purposes. However, the Landsat satellites have not proved to be adequate for many of the mapping applications which are usually performed with aerial photographs. The new SPOT satellite has, when used in the correct way for the right purposes, shown itself to be considerably more useful for both mapping and resources inventories. This paper deals with the subject how SPOT can be used for topographic mapping.

The suitability of SPOT for topographic mapping

The SPOT satellite, launched in 1985, significantly enhances the usefulness of satellite images. The design of the satellite itself, and the system around it, means that it can be used for applications in which only aerial photographs were used earlier. SPOT offers the following advantages over the earlier Landsat satellites:

- SPOT can be programmed. A program request can be made in advance, at a reasonable cost, for one particular scene or a large area. For instance, the Swedish Space Corporation (SSC) is currently conducting a nationwide coverage by panchromatic and multispectral SPOT images on behalf of the Indonesia Government under the terms of a three-year contract. Furthermore, over the past year all the major islands of the Philippines have been successfully covered by SPOT.

- SPOT has a side-viewing capability. This offers two advantages. Firstly it is possible to observe a scene of a requested area more frequently, the chances of obtaining a cloud free scene within a limited period of time increase. Secondly the side-viewing capability also makes SPOT capable of obtaining stereo pairs of images. A very good base-to-height ratio is obtainable, slightly better even than for super-wide angle aerial photographs.
- SPOT has a good spatial resolution. SPOT multispectral images have a pixel size of 20 meter's (vertical viewing) and panchromatic images have a pixel size of 10 meter's (vertical viewing).
- SPOT has a spectral sensitivity that is well-adapted to aerial photographs. The multispectral images can be made very similar to infrared colour photos, and the panchromatic images can be produced as ordinary b/w aerial photographs. The images can thus be used directly by personnel trained for interpretation of aerial photographs.
- SPOT has a good geometry. The CCD-technique makes the geometry of SPOT very stable and predictable. SPOT can be corrected extremely precisely to any used co-ordinate system.
- SPOT also has good radiometric properties with a good signal-to-noise ratio and a limited point transfer function. SPOT can be resampled and enlarged to scales of about 1:20 000 or 1:25 000 when used as an orthophoto background, and can be used for mapping on scales of 1:50 000 or 1:100 000 and smaller.

The use of SPOT images for the production of height information

The height information, i.e. information about the topography, is the main difference between topographic and thematic maps - although most topographic maps actually do have a thematic component. The height information consists mainly of height contours but also of single height values given for certain spots or areas. Advantages can be gained by constructing height contours from Digital Terrain Models (DTMs). A DTM could be utilized for more purposes than contours can.

Until recently DTMs were almost exclusively measured manually in aerial photographs. Highly expensive equipment, such as analytical plotters, are used for manual time-consuming interactive work. However, the manual approach is still natural as far as aerial photographs are concerned. In order to make automatic parallax measurements in aerial photographs possible, they have to be digitized, which results in a certain loss of quality and makes additional equipment necessary. This is not the case with SPOT images, which are originally received and stored digitally and have to be transferred into analogue photographic form in order to make measurements in analytical plotters possible. Transforming digital image data to analogue form always leads to a loss of radiometric information and often causes geometric distortions.

Consequently, the most natural approach when using SPOT images for topographic mapping is to make automatic measurements directly in the digital image data. This also appears to give the best results compared to analytical plotter measurements.

The DTM system at the Swedish Space Corporation

At the Swedish Space Corporation a method for automatic computation of heights directly from image data has been developed and implemented in a production environment, a Teragon 4000 image processing system with MIMA software. This system has extremely high performance as regards speed and accuracy. The average computation time for each point in the DTM is between 0.3 and 0.8 seconds, which in many cases is 5 to 10 times as fast as it is possible in an analytical plotter. The accuracy of the matching is approximately 0.25 pixels, corresponding to 2.5 meters in parallax in panchromatic SPOT images.

Not only heights are produced by the DTM system. The following products are produced simultaneously as an integrated part of the computations:

- Digital Terrain Models
- Orthophotos of the SPOT images
- An image showing areas with insufficient image information.

The fact that orthophotos are produced at the same time as the DTMs are computed increases the total production speed and decreases the cost. The image showing pixels with insufficient radiometric image information can be used for the identification of areas of low reliability in order to mark such areas (clouds, stereo shadows, major changes etc) in the final product.

The images are not oriented in the DTM system but in the precision correction system, prior to the height computations. This guarantees high precision of the orientation and enables a more parallel production.

The automatic method for computation of Digital Terrain Models

The basic problem to make automatic parallax measurements is equivalent of finding the local positions in the images with the best match. The best match has traditionally been measured by maximizing the correlation coefficient, or some other similarity function, between the grey-levels within a specified area, an image window. This method has now more or less been left by photogrammetric researchers. The lack of a theoretical base made it impossible to develop the old method into operation. Other matching methods, which still are under research, are based on the structure in the images. Borders, or other structure elements, are first extracted after which the extracted elements are matched to each other. The final DTMs are interpolated between the matched elements. However, these methods are not suitable for other photogrammetric purposes than extraction of approximate values as the, most essential, texture in the images not are used in the matching.

A least square matching method, introduced to photogrammetry in 1982 (Förstner), was a new starting point for research in order to develop operational methods for automatic parallax measurements. The least squares method have a lot of well-known and efficient mathematical tools connected to it, tools which, with some care, can also be applied to least squares matching of images. The Multi-Point Matching Method (Rosenholm 1986, 1987a) is a further development of the least squares matching method.

In the Multi-Point Matching Method many of the possibilities given by the least squares method have been used. In this method the points are not computed separately but are connected to each other through bilinear finite elements in a regular grid.

A most important element of the Multi-Point Matching Method is the introduction of additional weighted constraints. Constraints minimizing the curvature and minimizing the slope can be used. When areas are textureless, or there are to large discrepancies between the images, the constraints bridge these areas. Another important element in the method is data snooping of individual pixels. Pixels with to large radiometric differences are excluded with statistical technique. The data snooping technique and the constraints are both two necessary parts of the Multi-Point Matching Method which are interacting with each other. The data snooping excludes unwanted pixels and the constraints stabilizes the grid in weak areas.

Advantages of SPOT imagery in topographic mapping

SPOT images can be used for topographic mapping and the heights can be automatically extracted with the Multi-Point Matching method. Earlier systems for automatic parallax measurements have suffered from poor reliability. SPOT and our production systems offers the following advantages with regard to topographic mapping:

- Stable geometry, which makes precision corrections of extreme good quality possible.
- High spatial resolution.
- Good radiometry, which makes precise matching possible.
- State-of-the-art precision correction system at the Swedish Space Corporation, which is designed for a high production capacity while maintaining good quality.
- The Multi-Point Matching method, which has the following important elements:
 - o a theoretical basement in the least square method, which ensures effective use of image data, thus making high precision possible
 - o a well-defined mathematical model for the surface, which is allowing consistent results
 - o weighted additional constraints

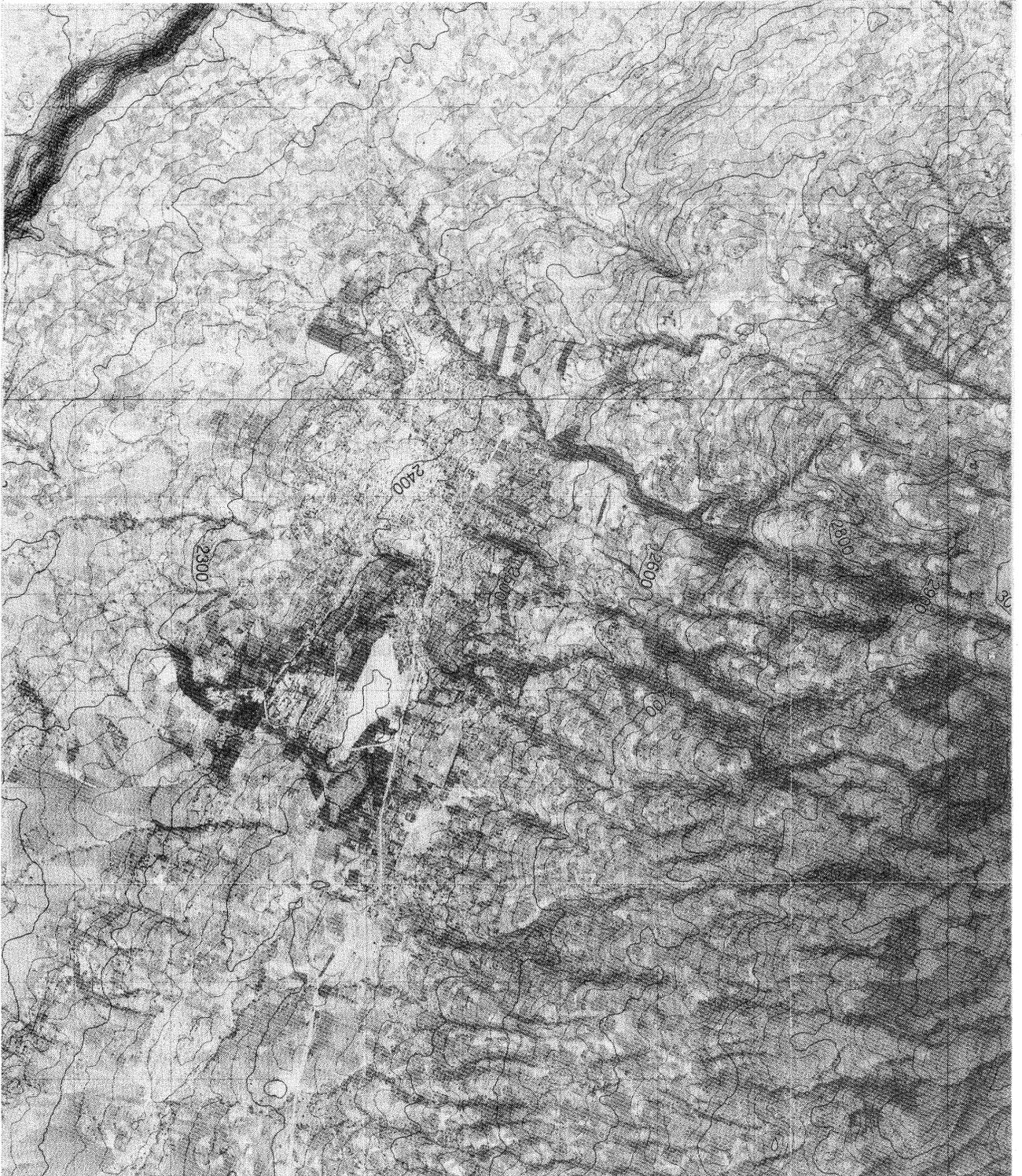


Figure. A part of a 1:50 000 orthophoto map sheet. The contours are automatically extracted from SPOT-stereo images at the Swedish Space Corporation. From the SPOT orthophoto and the contours ready printing originals are produced by the National Land Survey of Sweden.

- o data snooping, which, in combination with the weighted additional constraints, makes possible the high level of reliability
- o powerful image processing hardware, a Teragon system, which is essential for fast processing.

Topographic maps from space - A production chain

A topographic map does not only consist of height information. A simplified thematic classification, infrastructure, borders and boundaries are other common map elements. Much of this information can be extracted from SPOT images and complete topographic maps can be produced.

The production of topographic map sheets within the unique TOPSAT organization - a joint production organization comprising the Swedish Space Corporation and the Swedish National Land Survey with all production facilities located in the "Space Building" in Kiruna, northern Sweden - may be organized in the following way:

- 1) Reception of the image data at Esrange receiving station outside Kiruna.
- 2) Archiving of the SPOT images at Satimage Corporation, a subsidiary of the Swedish Space Corporation, in the "Space Building".
- 3) Precision correction of the images to the required coordinate system.
- 4) Computation of DTMs and orthophotos.
- 5) Other image-processing work, such as mosaicking of orthophotos and DTMs, computations of height contours from the DTMs, of stereo partners to the orthophotos etc.
- 6) Manual interpretation, or alternatively sometimes computer classifications, and complementary field work.
- 7) Production of printing originals from the orthophotos, the contour lines and the interpretation results.

All these production steps are performed in Kiruna and all those activities, except the reception of the SPOT images, are situated within the same physical building. TOPSAT is a unique production organization in the world.

Conclusions

The SPOT satellite makes efficient production of topographic maps in scales between 1:50 000 to 1:100 000 possible. Automatic extraction of DTMs, in the operational system at the Swedish Space Corporation, enables a streamlined production system of topographic maps, in connection to the SPOT receiving station in Kiruna, Sweden, in close co-operation with the National Land Survey of Sweden.

References

Förstner W., 1982. On the Geometric Precision of Digital Correlation. International Archives of Photogrammetry, Vol XXIV Com III, pp 176-189, Helsingfors

Rosenholm D., 1986. Accuracy Improvement for Evaluation of Digital Terrain Models. International Archives of Photogrammetry, Vol XXVI Com III, pp 573-587, Rovaniemi

Rosenholm D., 1987a. Multi-Point Matching Using the Least Squares Technique for Evaluation of Three Dimensional Models. Photogrammetric Engineering and Remote Sensing, Vol 12, No 2, pp 621-626

Rosenholm D., 1987b. Operational Computation of Digital Terrain Models from SPOT Images by Digital Matching Techniques, for Production of Topographic Maps in 1:50 000. 8th Asian Conference on Remote Sensing, Jakarta