DIGITAL ORTHOPHOTOS FROM IRS - PRODUCTION AND UTILIZATION

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ABSTRACT

The Sweden based GAF subsidiary Observation, Mapping and Monitoring AB (OM&M) has produced ortho-images based on IRS data on a routine basis since May 1997.

The Indian IRS-1C and 1D satellites are the first real multi-resolution optical satellites available on the market. The most well known sensor on IRS-1C/1D is the PAN sensor, with 5.8 meter resolution and a scene size of 70 km x 70 km. The multispectral sensor (LISS-3), has a resolution of 23.5 meters with a scene size of 142 x 142 km. The lowest resolution sensor (WiFS) has a resolution of 188 meters, with an swath width of more than 800 km. All three sensors are acquired with push broom technology, and is as such very well suited for precise geometric correction.

The orbital correction of the IRS PAN and LISS-3 data is based on geometrically raw data combined with orbital information from the satellite operator which is written as header files. The production is based on Leica / Helava's well reputed photogrammetric production system SOCET SET. This paper describes the production and application of ortho-corrected IRS-data within areas such as road mapping, topographic mapping, forestry and as a product in itself.

1 GEOMETRIC CORRECTION

Satellite image data has to a large extent been used in the form of standard corrected products. Such products are corrected for Earth rotation and to some standard Earth ellipsoid and projection and are commonly oriented along the track. The disadvantage with this kind of products is that it can not be directly combined with other geographic information and that the result can not be directly included into geographic databases and map systems. This way of working was considered acceptable for many applications - as long as the mapping was not carried out digitally in GIS or image processing systems.

Geometric correction of satellite image data can be carried out in two principally different ways. The simplest way (available in most standard image processing systems) is to apply a polynomial function to the surface and adapt the polynomials to a number of check points. To do this no information about the origin is needed. For satellite images with simple geometric conditions - near-vertical viewing and/or relatively flat areas - a low degree polynomial can give a sub-pixel result. Polynomial transformations of higher degrees are unreliable and are, almost ironically, called "rubber sheeting".

The alternative to polynomial methods is to do a correction based on an orbital model of the satellite track and the rotation angles of the instruments. Orbital correction has the advantage of being very stable and gives true ortho-images when Digital Elevation Models are used, also in very undulating terrain and with large viewing angles. However it is based on a rather complicated description of the orbit, it can basically only use geometrically raw data, and is dependent on the condition that accurate orbit and attitude information is delivered together with the image data.

The Sweden based GAF subsidiary Observation, Mapping and Monitoring AB (OM&M) is the first entity in Europe to offer Ortho-corrected IRS data on a routine basis. The production is based on Leica / Helava's well reputed photogrammetric production system SOCET SET. This article describes the production and application of ortho-corrected IRS-data.

2 FROM ORBITAL DATA TO MAP SYSTEM

2.1 The Image data

The Indian IRS-1C and 1D satellites are the first real multi-resolution optical satellites available on the market (National Remote Sensing Agency, 1995a). The lowest resolution sensor (WiFS) has a resolution of 188 meters, with an impressive swath width of more than 800 km. It is aiming towards the monitoring market.

The multispectral sensor (LISS-3), has a resolution of 23.5 meters in three Visible and Near Infra-Red bands and a resolution of 70 meters in a Short Wave Infrared band. The scene size is 142 x 142 km. LISS-3 is a sensor with an image size close to Landsat MSS, and a resolution and acquisition technology close to SPOT XS.

The most well known sensor on IRS-1C/1D is the PAN sensor, with 5.8 meter resolution and a scene size of 70 km x 70 km. A striking combination of high resolution and large coverage. All three sensors are acquired with push broom technology, and is as such very well suited for precise geometric correction.

The orbital correction of the IRS PAN and LISS-3 data is based on geometrically raw data in Super Structure format, combined with orbital information from the satellite operator which is written as header files. The PAN-sensor of IRS is observed through three different arrays of 4096 pixels width each. The raw data for PAN is received and delivered as three different strips, each 23.5 km wide. Due to the satellite's construction, there is an angle difference between the three strips of about a quarter of a

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degree along track, corresponding to more than half a second of orbital time. The overlap across track between the three arrays are in the range of 50-100 pixels and varies depending on factors like ground speed of earth rotation and the azimuth of the satellite ground track. Both factors are primarily latitude dependent.

LISS-scenes as well as WiFS scenes are delivered as single units, with the channels separated. Neither constitutes any principal differences in implementing for ortho-correction as compared to SPOT. Strict geometric correction of WiFS data is not yet tested in production.

2.2   Orbital Information

The orbital information is available in the Super Structure header. (National Remote Sensing Agency, 1995b) The information is usually given in arrays of 23 elements, each separated by one second of orbital time. The total length of 23 seconds is slightly larger than the length of a LISS-3 scene. Within this array, a start time for each scene will give the exact scene location. Data from six descriptive arrays are used in the ortho-correction procedures, i.e. the three co-ordinates and the three attitudes in each location along the arrays.

2.3   The Model

An Orbital Model for correction of optical satellite images which are obtained with push-broom technology, is based on establishing a direct connection between the image co-ordinates (usually given as orbital time along track and pixel number along the array) and the ground co-ordinates in any system. For any given ground co-ordinate the orbital description is updated to best fit the data. Ground co-ordinates are usually given in some projection, typically, but far from most frequently used in Europe, UTM. The ground co-ordinate of the control points is transformed into latitude and longitude on the used ellipsoid, followed by a transformation into geocentric coordinates.

The orbital description of the raw data is transformed to an Earth Centred Earth Fixed system - corresponding to geocentric geodetic systems. Difference in geodetic datum is taken into account. Locations of the orbit as well as the attitude angles are all transformed and given in the same geocentric system as the ground control. The relation between the image co-ordinates and ground co-ordinates are established. For each image line the relation is described through an ordinary central projection - in photogrammetry expressed as the co-linearity equation. The orbital description, including the attitudes, tie these central projections together. Orbital parameters are up-dated for best fit, in accordance with the least square method, to the ground coordinates.

2.4   Production Procedure - Quality Control

The production procedure is, independent of correction methodology, the most crucial issue for maintaining a high sustainable quality of the production. At OM&M we use uniform procedures for the production and quality control. The procedure includes the following steps.

1)   Ordering of geometrically raw data. IRS data is ordered from and pre-processed by our sister company Euromap in Neustrelitz near Berlin. The ordering procedure is standardised, using specifically designed written forms.

2)   Data import. The quality and correctness of the data is checked as an initial step. In case of IRS PAN images the tie points between the three arrays is measured.

3)   Selection of control points. Control points are usually extracted from existing maps or measured by GPS. The control points are selected in the image data according to a standardised pattern to ensure uniform results. At present approximately 15 points are used for a PAN scene, while 8-12 are used for LISS-3 scenes. Control points are always measured in groups of two or three. This enables reliable detection of errors in single points.

4)   Ground co-ordinate extraction. Ground co-ordinates are digitised from maps with a high precision equipment handling deformations in the printed maps better than standard digitising tables. Alternatively pre-selected points are measured by GPS. The quality of the ground control is decisive on the quality of the final result!

5)   Triangulation. Based on the measurements of ground control points in the images and of the corresponding ground co-ordinates - and in the case of IRS Pan data the tie points between the arrays - an adjustment is done. In the adjustment the image measurements, the ground co-ordinates as well as the orbital information are treated as weighted observations.

6)   Ortho-correction. Based on the new geometric description obtained from the triangulation, the image is transformed into the map projection requested. By projecting the image on a DEM overlaying the ellipsoid surface an ortho-image is obtained.

7)   Quality check. In all images delivered independent check points are measured as a final check of the result. This gives an unbiased estimate of the obtained result. This in contrast to commonly used error estimates obtained from the adjustment - which is regularly a grave underestimation of the true errors!

8)   Delivery Certificate. Together with the delivered scenes, a Delivery Certificate is sent. The Delivery Certificate contains all basic information about the scene, such as sensor, date, scene co-ordinates, etc. In addition the accuracy figures for the adjustment and the independent check points are given.

2.5   Results

The quality of the ortho-correction is primarily dependent on the quality of the ground control. At present we can process the IRS PAN images in two different fashions. In the first we mathematically merge the three arrays before the correction. The disadvantage is systematic errors in the range of 3-4 meters which remains not modelled. Alternatively the three arrays can be treated individually. In the latter case the ground control point requirements are high both in respect to number and especially quality

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but strikingly good results in the range of 2-3 meter accuracy are possible. A method combining the advantages of these two strategies is under development.

As part of the activities we have continuously been carrying out tests of the results. The most extensive test example is from a PAN scene in the Stockholm area. In an IRS PAN scene from the 7th of June 1997, altogether 51 control and check points were selected. The points were measured by differential GPS during two days of field work. The results show consistent accuracy around 4 meters, proving the relevance of the models used. Using the same configuration and very recent Swedish topographic maps, practically the same results were obtained.

The LISS-3 sensor appears as one of the most convenient sensors for orbital geometric corrections on the market. The reason is obvious, the push-broom technology in combination with a wide swath creates a very stable geometric model. Regular tests with independent check points shows repeatedly a real end product accuracy of 11-12 meters in Northing and 9-10 meters in Easting, i.e. below half a pixel.

3 APPLICATIONS

3.1 Why Ortho-Images?

Satellite remote sensing applications have been carried out for more than 25 years, more or less, operationally. Most of this has, especially in the early days, been done without any complicated geometric correction. Why is suddenly something like ortho-correction needed? It has worked before without it, there is no reason that it will not work in the future. This is satellite remote sensing, not mapping from aerial photographs. Is this something made up by some meticulous photogrammetrist?

Maybe this is what you also think?

The reasons for using geometrically correct satellite data are manifold.

In the early ages of remote sensing the concentration was on extracting the thematic information. The results of this thematic information was commonly utilised as separate information for some specific purpose. The access to geometric correction was limited due to methodological constraints as well as processing capacity. In addition there has been a misbelieve that resampling destroyed, something regarded as, original radiometric measurements. The common way to carry out a project was manual interpretation (or digital classification) of standard corrected data which was then transferred, somehow, to a map system.

Today geographic information is increasingly stored as digital databases. Geographic information is analysed in GIS-systems. Often many layers of information, from different sources, are combined in the analysis. If the geometric accuracy is not sufficient in relation to the application this analysis is practically meaningless. *The first reason that precise geometric correction is needed is thus to enable the combination of multiple geographic sources.*

Another consequence of storing geographic databases digitally is, in combination with new applications, the requirements on revision. Topographic maps, the base for most other geometric information, have in the past been revised with embarrassingly long intervals. Planned revision cycles of five or ten years have rarely been fulfilled. In the new information dense world geographic information is playing a much more central role than earlier, not only for public authorities, but much more for the broader public and for commercial entities. Will anyone use ten year old information on Internet, for car navigation or for environmental impact studies? To revise geographic information frequently without a close to perfect fit between the old database and the image material would be too expensive, time consuming and result in quality which is poor. *The second reason that precise geometric correction is needed is thus to enable frequent and efficient revision of geographic databases.*

Earlier satellite images were primarily used for thematic mapping, often in scales between 1:250,000 to 1:100,000. The data itself had a resolution of between 10-30 meters. Today we have access to 5 meter resolution data from IRS-1C and IRS-1D, and we are soon to have access to 1 meter resolution data from Ikonos and other sensors. Satellite data is increasingly used for new applications requiring higher geometric accuracy, as well as being directly applicable in fields where only aerial photography could be used before, such as topographic base mapping of full standards. *The third reason that precise geometric correction is needed is thus to enable use of high resolution data sources in applications earlier restricted to traditional technologies.*

3.2 Why IRS-1C/1D?

IRS-1C and IRS-1D images have proved to be a major step in the utilisation of satellite image data. It represents a unique slot in the product range that the Earth Observation industry can now offer to users and producers of Geographic information. It has a higher resolution and scene size than SPOT, one PAN scene contains four times as many pixels, and one LISS-3 scene is more than five times as large as a SPOT XS scene. In comparison to the soon-to-come very high resolution satellite images it has a big advantage with the large 70 km x 70 km coverage in combination with the 5.8 meter resolution. A major advantage, not commonly realised, is the way it is operated in Europe. The Pan sensor, with a side-viewing capability but a limited operational flexibility, is in principal programmed to be received close to vertical and within the limitations of the twice as wide LISS-3 scenes. The PAN, the LISS-3 and the WiFS sensors are all received at every pass and simultaneously and the case will be the same for IRS-1D. This means three things. Firstly it means that a base coverage is obtained significantly faster than if a lot of programming would be carried out. Secondly it means that merged 5 meter colour images can be produced from PAN and LISS-3, from basically all passes. Thirdly it means that ortho-corrected PAN data can be produced from Digital Elevation Models of relatively low accuracy; an r.m.s. height accuracy of 40-50 meters is sufficient corresponding to elevation models with a density of around 250 meters or, in most cases, less.

3.3 What is it good for?

What are the applications for ortho-corrected IRS data? Some examples from our pocket of experience.

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3.3.1   Road Data

Production of navigable road databases is becoming a prime example of the use of ortho-images from IRS. OM&M, has delivered an IRS-1C coverage of the Southern part of Sweden for the major European GIS company, Tele Atlas (Corbley, 1998). Tele Atlas, is the market leader in producing navigable road data bases for Car Navigation systems in Europe. A major problem for production of such data bases are the availability of source material. In the past various data sources like topographic maps, city maps, existing road data bases, aerial ortho-photos, in one case SPOT data, etc. has been used for producing the image data bases. For areas outside cities IRS-1C and IRS-1D constitutes an homogeneous and relevant data source with a sufficient accuracy, of course under the condition that it is ortho-corrected.

Ortho-corrected IRS data can also be used for identifying areas in need of up-dating. In the future it is estimated that the navigable road data bases should be up-dated two times per year. A possible way to do this is to first identify the areas to be up-dated in lower resolution and then doing the actual revision with higher resolution material. LISS-3 and, in urban areas, IRS PAN data, can be utilised for identifying the areas in need of updating. IRS PAN data, aerial photographs or soon Ikonos data, can be acquired for those areas and be used for the revision.

3.3.2   Topographic Mapping

The problems related to Topographic Mapping has similarities with navigable road data bases. Topographic maps are the traditional base material for basically all geographic information, except for the largest scales. Topographic Maps have been revised with very long time intervals almost without exception around the world. Presently Topographic maps are transferred to and stored as databases. Besides being sold as paper copies they are becoming available on data media's. This will put totally new requirements on the topographic maps - the databases. Similar to the road databases the topographic maps will need frequent up-dating while they are provided on digital media (Rosenholm, Mahlander, 1997). The procedures and requirements are also similar to the road databases, first find the changes, get data relevant for revision of the actual objects and do the revisions. Ortho-corrected IRS-1C/1D data will be used for firstly identifying and then partly carrying out the revision.

3.3.3   Operational forestry

The industry in Sweden with the most long term economical impact is the forestry sector. In Sweden more than 60% of the area is forest covered. In addition almost all of these forests are commercially used and can basically be regarded as slow growing plantations. The intense way of using the Swedish forests requires very detailed and up-to date information. The commercial entities as well as the Swedish forest authorities are in need of such information (Persson et al, 1998). The traditionally used 1:10,000 and 1:20,000 forest maps are transferred to geographic data bases. Yearly, or biannual, up-dating is becoming required. Ortho-photo from aerial photographs are usually too expensive to be acquired for a single purpose, bought from stock they are often too old. Ortho-corrected and merged colour images in 5 meter resolution, produced from IRS PAN and LISS-3 data is a solution that will be one, if not even the most, important solution in Northern European forestry.

3.3.4   Satellite images in maps and databases

A still underestimated use of ortho-images is the combination with other, usually vector, based information. This is nothing specifically new. The Swedish Land Survey has for many decades produced their 1:10,000 and 1:20,000 topographic maps, not only by means of ortho-photos, but also with the ortho-photos integrated in the maps.

In Estonia, Latvia and Lithuania totally new 1:50,000 map series with line information on an ortho-image background were produced from SPOT. The content was partly restricted compared to conventional line maps. Nevertheless it would have taken much more time and much more money to do the same with traditional technology. Maybe these three "new" European countries would not yet have had their own maps, if not for space based ortho-images.

3.3.5   Other applications

The conditions outlined in the above examples are also valid in most other GIS applications. High precision ortho-correction is required in order to be able to combine satellite images directly with the geographic databases, both for analysis and display. Non traditional markets for remote sensing have already been opened up by the GIS industry. Satellite images have, and will have, extensive use within areas such as damage and risk assessment within the insurance industry, travel and tourism especially in combination with road data bases, prediction and assessment of natural catastrophes, as well as the already well established applications for cell planning for the Telecommunication industry.

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