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Photogrammetric processing of satellite scanner imagery

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Currently role of various types of scanner imaging systems in photogrammetric applications is steadily growing. Photogrammetric processing of scanner images sufficiently differs from the case of central projection photographs due to dynamic nature of image acquisition. This paper is devoted to describe practical experience in the development of computational procedures for digital photogrammetric system PHOTOMOD (RACURS company, Russia).

The most common type of scanner satellite imaging systems is a pushbroom sensor (SPOT – HRV, HRVIR, HRG; IRS – PAN; Terra – ASTER; EROS – NA-30; Ikonos), that's why such systems are mainly in question in this paper. But even among digital imagery products acquired by pushbroom sensors there is a wide variety in the content of ancillary data set, which the images are supplied with. Depending on the data sets two main approaches may be applied: physical (also known as "geometrical") and mathematical (sometimes called "algebraic").

Physical approach consists in detailed image acquisition process modeling including motion of spacecraft center of mass, satellite rotation about it and, that is most important, in using precise geometric camera model.

Since a single image is acquired on rather short part of the trajectory, it can be modeled either by orbital motion equations or by polynomial approximation. In either case it's almost always necessary to know relation between image line number and its acquisition time. Although they are supposed to be linearly dependent for pushbroom imaging system, usually ephemeris/attitude data are given with respect to time (sometimes indirectly – due to using inertial reference frame), but photogrammetric processing requires knowledge of sensor position in relation to image line number.

Attitude is usually modeled by a polynomial (of low degree – linear or quadratic) depending on image line number or its acquisition time. Often image is supplied with angular velocities of the sensor rotation, but when processing imagery of not very high-resolution (about 10 m) using ground control points for sensor orientation refinement, according to gained experience, this data may be ignored without significant accuracy loss.

The most important condition for the possibility to realize physical approach to photogrammetric processing is availability of the geometric camera model that gives vector of sight (related to the reference frame fixed with respect to sensor) as a function of pixel number on the image line. The function may be defined by a table with values specified on a lattice with some step along image line (or only for the extreme pixels of an image line), and linear interpolation should be used to calculate the vector between the nodes of the lattice. Besides that, some geometric model may be used, for example, planar analogue of central projection. In any way, the model should be as accurate as possible because its refinement during bundle adjustment makes this procedure unstable and less accurate. If, nevertheless, the refinement is really necessary, planar central projection model already mentioned is suitable because it contains only two parameters to be estimated ("efficient focal length" (expressed in pixels) and number of the "principal pixel") and their initial values can be easily obtained.

Using these three models one can calculate vector of sight and sensor position as a function of pixel coordinates of an image point: first, camera geometric model gives sight vector direction in the sensor reference frame, then attitude model lets to transform the vector into, generally speaking, geodetic reference frame, and motion model provides us with sensor position.

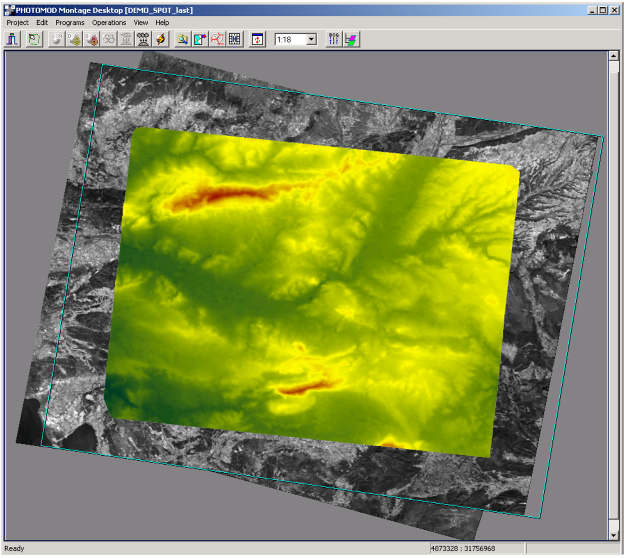
When all the models listed above are elaborated and initial values of their parameters are estimated, bundle adjustment procedure should be performed. In PHOTOMOD system currently the procedure is carried out for each image separately and is based on assumption that ray, whose direction (vector of sight) and vertex (sensor position) are calculated using ground control point coordinates on the image should pass through the point on the earth. This procedure is performed iteratively by least squares method and requires from tens to thousands iterations depending on models which were applied.

Since the satellite position and sight vector are known as functions of image point coordinates, it's possible to solve two main photogrammetric problems:

- to calculate image coordinates from ground coordinates (what is necessary for forming orthoimagery) through iterative process using a single image
- to obtain ground coordinates of a point from its image coordinates on a stereopair, what is necessary for digital elevation model computation (Picture 1 gives an example of digital elevation model derived from panchromatic SPOT stereopair). This operation is called triangulation; it should be taken into account that the calculated rays will not intersect in fact, therefore some additional considerations should be used to get the ground point. In the simplest case we can suppose that both rays are obtained with the same precision and the point in question is the middle of their common perpendicular.

As opposed to the physical modeling, mathematical approach can be applied, when only imagery but no ancillary data are available. This method consists in using direct expressions for pixel coordinates of an image point as a function of its ground coordinates. Structures of the expressions are determined by some assumptions (usually the assumptions are very general, for example, that some value changes linearly or very slowly, and therefore they impose rather strong limitations) about imaging system. The expressions contain a set of numerical parameters that are to be estimated using ground control points by adjustment procedure based on least-squares method. Then the first of two main photogrammetric problems, listed above, can be solved directly using these expressions, and the second problem is equal to set of four equations with three unknowns. Often the equations can be transformed to linear ones, and then the generalized solution of the equations set is easily obtained using least squares method.

Comparison of these two approaches shows, that mathematical one is simpler (and therefore faster), requires no ancillary data and consequently this approach yields more universal algorithms. The last assertion means that such algorithm can be applied without modification to a rather wide class of imaging systems, in contrast with the physical approach, which should take into account many specific features of each system. For imaging systems with ground resolution about 10 m accuracy obtained may be almost the same, but, of course, since physical approach is stricter, usually it gives better results. Another advantage of physical approach is that it requires significantly fewer amounts of ground control points (see Table 1; it should be noted, that ground points coordinates was gathered using maps of scale 1:25000 in the case of IRS imagery and 1:50000 in the case of SPOT; so final accuracy was sufficiently affected by the errors in the ground control points coordinates).



Picture 1: An example of digital elevation model derived from SPOT stereopair by digital photogrammetric system PHOTOMOD.

Sensor (mission) Mode (resolution)	Processing method	Number of GCPs RMS: plane/height	Number of check points RMS: plane/height
HRV (SPOT-1) PAN (10m)	Geometric	15 5.5m / 3.8m	57 11.9m / 9.0m
HRV (SPOT-1) PAN (10m)	Geometric	5 3.9m / 2.4m	23 8.7m / 2.9m
HRV (SPOT-1) MS (20m)	Geometric	4 16.0m / 5.6m	24 24.1m / 22.9m
HRV (SPOT-1) MS (20m)	Algebraic	10 27.0m / 23.7m	18 27.2m / 40.5m
PAN (IRS-1C) PAN (5m)	Algebraic	15 8.3m / 2.5m	32 18.3m / 9.6m

Table 1: The difference between physical (geometric) and mathematical (algebraic) approaches to photogrammetric processing of satellite scanner imagery

Nevertheless it seems obvious, that due to one meter and sub-meter resolution imaging systems the situation will radically change. Simple algebraic formulas, such as expressions of projective transformation, which are often used now in the scope of mathematical approach, raise doubt to be able to provide results with accuracy adequate to image resolution. Really, many of simple structured formulas used in this approach may be obtained by physical modeling of image registering process with very rigid conditions – for example, in assumption of uniform and straightforward motion of a satellite with no rotation about its center of mass during image acquisition. The errors, caused by such rough model, was negligible in many cases due to smooth motion and precise stabilization of the satellite, but in case of high resolution imagery it will not have a place. Therefore those expressions, which cannot take into account nonlinear nature of some processes, will become inconsistent.

Since volume of sales of high-resolution imagery depends on availability of photogrammetric systems, which support its processing, remote sensing data provider should supply imagery with all the necessary ancillary data, described above.

There is another question closely related to the product data content. It's the problem of provided data format. Current situation is that every data provider uses own format with specific content of ancillary data. In fact both data users (including software developers) and data providers are interested in some universal, but extendable, data format, which has common (mandatory) part and additional part. The first should contain standard data that allow performing processing using physical approach, while the second may include some unique advanced or special information. Such approach will guarantee that any data, which are stored in this format, are suitable for rigorous photogrammetric processing, and, on the other hand, data supplier may believe that any standard software will be able to fulfill this processing.