Changing perspective of aerial photogrammetry

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1. Introduction

Much has happened in aerial photogrammetry and remote sensing for topographic mapping tasks over the last few years. In the *sensor domain* the most noteworthy developments comprise

- the development and successful commercial use of digital aerial cameras and of laser scanners,
- the possibility to measure image orientation parameters directly in the air by means of a combination of GPS and inertial measurement techniques,
- the availability of sub-meter imagery from space on a regular basis.

As far as the *generation of geospatial information* from imagery is concerned, a number of trends can be observed:

- a larger degree of automatic processing,
- a closer link to GIS, including update and refinement of existing GIS data bases,
- the largely increased demand for digital imagery and geospatial data for use in the internet, exemplified by applications such as Goggle Earth and Microsoft's Virtual Earth.

Without any doubt, the automatic generation of geospatial information in conjunction with a closer link to the GIS world is the most demanding of the mentioned trends, especially if real-time applications such as disaster relief operations are to be handled. Such tasks can only be achieved on the basis of digital images, and sometimes need direct height information. Therefore, the development of digital aerial cameras and of laser scanners can be seen as pre-runners to solve the mentioned tasks. While this is known to be a notoriously difficult problem, some partial solutions exist, which are being successfully used in our field. The focus of this article lies on the automatically producing geospatial information and describes the scientific background of the field as well as some applications and future directions.

2. Background

The automatic generation of geospatial information is the extraction of information from images, relevant for a given application, by means of a computer. Photogrammetric image processing is divided into two aspects, i.e. the *geometric/radiometric image evaluation* and *image analysis*. Geometric/radiometric image evaluation comprises image orientation, the derivation of geometric surface descriptions and orthoprojection. Image analysis contains the extraction and description of three-dimensional objects. When using digital images, the borders of geometric/radiometric image evaluation and image analysis become blurred, mostly because due to automation the formerly decisive manual measurement effort has lost much of its significance. Therefore, already during the orientation phase a point density can be used, which is sufficient for some digital surface models (DSMs).

2.1 Geometric/radiometric image evaluation

Methods for the integrated determination of image orientation, DSMs, and orthophotos are known for some time, but for the sake of clarity the various steps shall be looked at separately in the following.

The components of image orientation are the sensor model, i.e. the mathematical transformation between image space and object space, and the determination of homologous image primitives (mostly image points). As far as the sensor model is concerned, the central projection as a classical standard case in photogrammetry must be distinguished from line geometry.

In the context of bundle adjustment the central projection is traditionally described by means of collinearity equations. The determination of homologue points is almost exclusively done by digital image matching. The methods for aerial images and for the satellite sector are almost fully developed and are available for practical purposes under the term “automatic aerial triangulation”. It should be noted that the automatically generated image coordinates of the tie points are often interactively supplemented or corrected.

As an alternative to aerial triangulation the direct and integrated sensor orientation were thoroughly investigated in the last decade. In both cases data from GPS receivers and IMUs (inertial measurement units) are used for determination of the elements of exterior orientation. For direct sensor orientation these data replace tie and (more importantly) also ground control points and thus the entire aerial triangulation. For integrated sensor orientation all information is used in a combined adjustment.

Like image orientation the derivation of geometric surface descriptions from images is based on digital image matching. If a digital terrain model (DTM) is to be derived from the DSM, interfering objects (for the terrain these can be buildings, trees etc.) must be recognized and eliminated. At present this task is solved by comparatively simple image processing operators and statistical methods. For aerial and satellite images DTM generation is commercially available in nearly every photogrammetry software package. As in image orientation, the automatic step is usually followed by a post-editing phase to eliminate blunders and fill in areas in which matching was not successful.

Orthoprojection, the projection of a central perspective image to a reference surface, mostly a horizontal plane, is a standard task in photogrammetry: Recently, automatic solutions for so-called “true orthos” have become available. True orthos are orthophotos for which a high quality DSM was used for differential rectification, instead of a traditional DTM, and where occluded areas are filled in from neighbouring images. As a result, for example, roofs and bridges are depicted at their geometrically correct position, and building walls are not visible.

2.2 Image analysis

Image analysis can be defined as the automatic derivation of an explicit and meaningful description of the object scene depicted in the images. For this purpose, individual objects such as roads and buildings must be recognized and described. This recognition needs prior knowledge of objects in terms of models, which must be made available to the machine prior to starting the automatic process. Alternatively, they can also be learnt in a first step of the process itself. In order to set up useful models, geometric and radiometric information on the various objects must be collected and adequately represented. For aerial imagery, the larger the scale of the images to be analysed and the more details are required, the more important is geometric information, as one more and more enters the domain of human activity, which can be characterised by linear borders, symmetries, right angles, and other geometric aspects. For smaller resolutions, however, radiometric and spectral attributes dominate, which explains the good results of multi-spectral classification for satellite images of coarser resolution as well as the inferior results of the same technique for high resolution satellite and aerial images.

The set up of the object models is a major problem of image analysis. At present, despite significant research effort it is still not clear a priori, which elements of an object and scene description need to be taken into account to build a useful model. Recently, more and more statistical methods are used in knowledge acquisition and representation. Presently, these attempts are still provisional, however it is obvious that an efficient automatic generation of models is a decisive prerequisite for the success of image analysis approach.

Another possibility for introducing a priori knowledge is based on the assumption that images are normally analysed for a certain purpose, pre-defined at least in its main features. This is, where the mentioned link to GIS can help. In GIS, the available information is described in object catalogues, which contain relevant information for formulating the object models for image analysis. It is sometimes also postulated that object models for image analysis should be set up hierarchically in a similar way, as they are described in object catalogues: the upper level discerns only coarse context areas, such as settlements, forests, open landscape, and water bodies, and a refinement then follows within the respective context area.

Available GIS data rather than only descriptions in feature catalogues may also be used as part of the knowledge base. In this way, the GIS data can also be checked for correctness and completeness. An example is shown in Figure 1, where road data are superimposed with an orthophoto. Roads depicted in green have been automatically checked and verified by the developed system; roads in red were not recognised automatically and need to be checked by a human operator. The formal description of data quality is still an open, but important aspect for this approach.

In recent years, important progress was made in image analysis, even though a breakthrough in direction of practical applications has not been achieved yet. Under certain conditions single topographic objects like roads in open terrain, buildings and vegetation can be successfully extracted automatically. The present status of image analysis can be summarized as follows:

- simultaneous use of multiple images, combined with early transition to the three dimensional object space, simultaneous use of point, line and area information through projective geometry,
- rich modular object modelling encompassing geometric, radiometric, and spectral information,
- simultaneous use of multiple image resolutions and degrees of detail in object modelling in terms of multiscale analysis,
- simultaneous interpretation of different data sources, such as single images and image sequences with geometric surface descriptions and two dimensional maps,
- modelling of context and complete scenes instead of single object classes,

- investigations regarding formulation and use of uncertain knowledge, for example based on graphical models such as Bayes nets, fuzzy logic, and evidence theory to enable automatic evaluation of the obtained results in terms of self-diagnosis,
- investigations into automatic production of knowledge bases using machine learning.

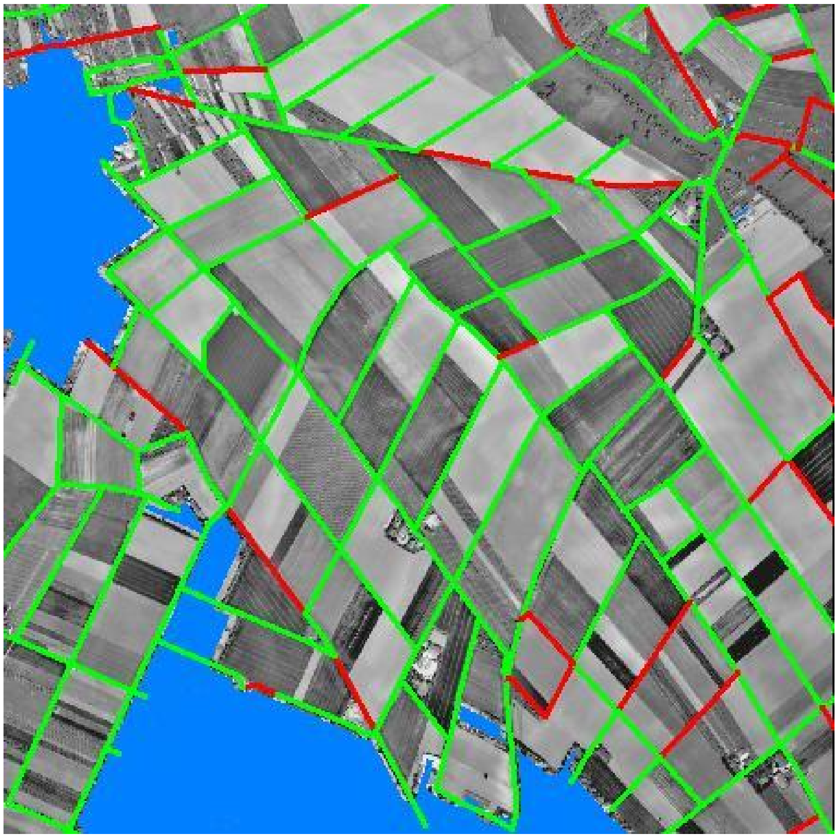

Figure 1: Orthophoto with superimposed road network from a GIS database. Roads depicted in green were automatically detected in the orthophoto and could thus be verified, for roads in red this was not the case; the red roads need to checked by a human operator.

3. Applications and future directions

The automatic generation of geospatial information from images finds a host of applications in all areas dealing with the determination of three-dimensional coordinates from as well as the interpretation of imagery. Traditionally the most important application of photogrammetry was topographic and cartographic mapping. Recently, new technical developments such as digital still and video cameras and new demands such as environmental monitoring and disaster management have paved the way for many new applications.

Mapping and Geographical Information Systems (GIS) still are the key applications today. Other disciplines such as agriculture, forestry, environmental studies, city and regional planning, 3D city modeling, geology, disaster management and homeland security also increasingly make use of automatic data acquisition from aerial and satellite images.

However, in spite of a large body of successful research in recent years practical applications of fully automatic systems do not seem realistic in foreseeable future. Semi-automatic procedures, however, begin to be used successfully. Contrary to fully automatic methods, semi-automatic methods integrate the human operator into the entire evaluating process. The operator mainly deals with tasks which require decisions (e.g. selection of algorithms and parameter control), quality control, and – where required – the correction of intermediate and final results.

It is anticipated that these semi-automatic approaches will be established in practical work within the next few years. In this regard, a proper design of the man-machine interface (MMI) will probably be of greater importance to the users than the degree of automation, provided that the latter allows for more efficiency than a solely manually oriented process.