Data Acquisition

► Photogrammetric Applications

Data Acquisition, Automation

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Synonyms

Automatic information extraction; Image analysis; Scene analysis; Photogrammetry

Definition

Automatic data acquisition 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 (3D) objects. A strict separation of both areas is possible neither for manual nor for automatic photogrammetric image processing.

Historical Background

In the past, geometric/radiometric image evaluation and image analysis were two clearly separated steps in the photogrammetric processing chain. Using analogue imagery, *automation* was understood as a supporting measure for a human operator, e. g., by driving the cursor automatically to a predefined position in image and/or object space to capture well-defined tie points or to speed up image coordinate measurement of ground control points or digital terrain model (DTM) posts. The first successful attempts towards a more elaborate role for the computer became commonplace once analogue images could be scanned and subsequently processed in digital form. In this way, interior and relative orientations, as well as large parts of aerial triangulation and DTM generation, became candidates for a fully automatic work flow. The recent development of digital aerial cameras inspires hope for further automation in the image analysis step.

Scientific Fundamentals

When using digitized or digitally acquired images, the border between geometric/radiometric image evaluation and image analysis becomes blurred, mostly because, due to automation, the formerly decisive manual measurement effort has lost much of its significance. Therefore, already in the orientation phase a point density can be used, which is sufficient for some digital surface models (DSMs). Methods for the integrated determination of image orientation, DSMs, and orthophotos have been known for some time, but for the sake of clarity the various steps shall be looked at separately here.

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. It should be noted, however, that the resulting set of equations is nonlinear in the unknown parameters. Starting from these observations, and from the known problem of deriving initial values for image orientation, especially in close-range photogrammetry, alternative formulations for the central projection were examined, based on projective geometry [1]. If necessary, the results can be used as initial values in a subsequent bundle adjustment. Alternative linear methods are also in use with satellite images, where rational polynomials play a certain role.

The determination of homologue points is almost exclusively done by digital image matching. While in close-range photogrammetry this task is still a matter of active research due to the variable image perspectives and the large depth range, 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 global positioning system (GPS) receivers and inertial measurement units (IMUs) are used for determination of the elements of exterior orientation [2]. 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. In close-range photogrammetry, coded targets play a central role as ground control points, since their position in the images can be determined fully automatically.

Like image orientation the derivation of geometric surface descriptions from images is based on digital image matching. If a 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 postediting phase to eliminate blunders and fill in areas in which matching was not successful. In close range, the problem of surface determination is different. Owing to smaller distances to the objects, more flexibility exists regarding the selection of sensors and evaluation method. Examples are the well-known coded light approaches and various so-called shape-from-X procedures, where X stands for motion, focus, contours, shading, and texture.

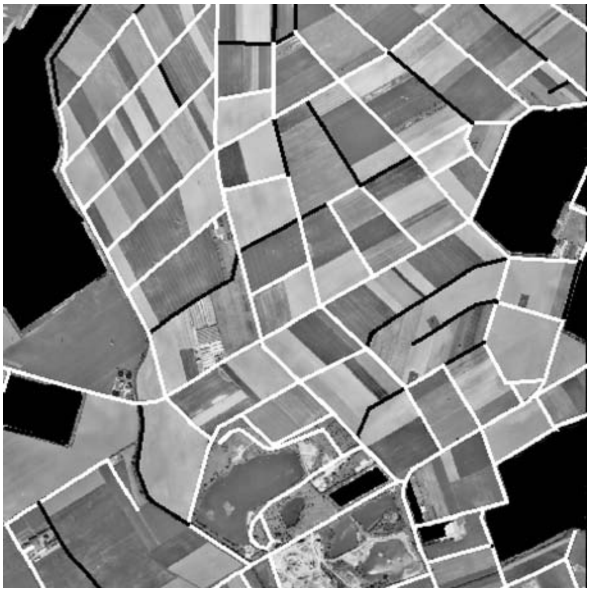
Orthoprojection, the projection of a central perspective image to a reference surface, mostly a horizontal plane, is a standard task in photogrammetry: Recently, automatic solutions for so-called true orthos have become available. True orthos are orthophotos for which a high quality DSM has been used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

Image analysis can be defined as the automatic derivation of an explicit and meaningful description of the object scene depicted in the images [3]. 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 analyzed and the more details are required, the more important is geometric information, as one increasingly enters into the domain of human activity, which can be characterized 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 multispectral 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 in 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 being 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 image analysis to succeed altogether.

Another possibility for introducing a priori knowledge is based on the assumption that images are normally analyzed for a certain purpose, predefined at least in its main features. In geographical informational systems (GIS), for example, 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 Fig. 1, where road data are superimposed with an orthophoto. Roads depicted in white have been automatically checked and verified by the developed system; roads in black were



Data Acquisition, Automation, Figure 1 Orthophoto with superimposed road network from a geographical informational systems (GIS) database. Roads depicted in *white* were automatically detected in the orthophoto and could thus be verified, for roads in *black* this was not the case; the *black* roads need to checked by a human operator

not recognized automatically and need to be checked by a human operator [4]. The formal description of data quality is still an open, but important aspect for this approach.

In recent years, important progress has been made in image analysis, even though a breakthrough in the direction of practical applications has not yet been achieved. 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 [5]:

- Simultaneous use of multiple images, combined with early transition to the 3D object space, simultaneous use of point, line and area information through projective geometry
- Rich modular object modeling encompassing geometric, radiometric, and spectral information
- Simultaneous use of multiple image resolutions and degrees of detail in object modeling 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;
- Modeling 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

Key Applications

Automation in data acquisition from images finds a host of applications in all areas dealing with the determination of 3D coordinates as well as the interpretation of imagery. Traditionally, the key application of photogrammetry has been 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 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. In the close range, applications range from industrial metrology, location-based services (LBS), autonomous navigation and traffic monitoring, to architecture, archeology, cultural heritage and medicine.

Future Directions

In spite of a large body of successful research in recent years, practical applications of fully automatic systems do not seem realistic in the foreseeable future. Semiautomatic procedures, however, are beginning to be used successfully. Contrary to fully automatic methods, semiautomatic methods [6] 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 semiautomatic approaches will be established in practical work within the next few years. A proper design of the man–machine interface 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.

Cross References

► Photogrammetric Methods
► Photogrammetric Sensors

Recommended Reading

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Data Analysis, Spatial

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Synonyms

Spatial analysis; Geospatial analysis; Geographical analysis; Patterns; Anamolies; Spatial interaction; Point patterns; Geostatistics; GeoDa; Geographically weighted regression

Definition

Spatial data analysis refers to a set of techniques designed to find pattern, detect anomalies, or test hypotheses and theories, based on spatial data. More rigorously, a technique of analysis is spatial if and only if its results are not invariant under relocation of the objects of analysis—in other words, that location matters. The data that are subjected to spatial data analysis must record the locations of phenomena within some space, and very often that is the space of the Earth's surface and near-surface, in other words the geographic domain. However, many methods of spatial data analysis can prove useful in relation to other spaces; for example, there have been instances of methods of spatial data analysis being applied to the human brain or to the space of the human genome. The terms spatial data analysis, spatial analysis, and geographic analysis are often used interchangeably. Spatial data analysis overlaps very strongly with spatial data mining. Some authors use the latter term to refer specifically to the analysis of very large volumes of data, and to imply that the purpose is the detection of pattern and anomalies—in other words hypothesis generation—rather than the testing of any specific hypotheses or theories. In this sense spatial data mining is more strongly associated with inductive science than with deductive science. However to other authors the terms data analysis and data mining are essentially synonymous.

Historical Background

Modern interest in spatial data analysis dates from the 1960s, when the so-called quantitative revolution in geography was at its peak. A number of authors set about systematically collecting techniques that might be applied to the analysis of geographic data, in other words to patterns and phenomena on the Earth's surface, drawing from the literatures of statistics, geometry, and other sciences. Berry and Marble (1968) published one of the first collections, and included discussions of spatial sampling, the analysis of point patterns, the fitting of trend surfaces to sample data in space, measures of network connectivity, Monte Carlo simulation, and measures of spatial dependence. Other early texts were written by Haggett (1966), Haggett and Chorley (1969), King (1969), and Taylor (1977). The topic of spatial dependence quickly surfaced as one of the more unique aspects of geographic pattern, and Cliff and Ord (1973) unified and extended earlier work by Moran and Geary into a comprehensive treatment.

Many of these early efforts were driven by a desire to find general principles concerning the distribution of various types of phenomena on the Earth's surface. For example, Central Place Theory had postulated that under ideal geographic and economic conditions settlements on the Earth's surface should occur in a hexagonal pattern. Many methods of point pattern analysis were developed and applied in order to detect degrees of hexagonality, without success. Other researchers were interested in the morphological similarity of patterns across a wide range of phenomena, and the implications of such patterns for ideas about process. For example, Bunge (1966) describes efforts to compare the geometric shapes of meandering rivers with roads in mountainous areas, and others compared river and road networks to the geometry of branching in the human lung.

Another quite different direction might be described as normative, or concerned with the design and planning of systems on the Earth's surface. The field of location-allocation modeling developed in the 1960s as an effort to develop techniques for the optimal location of such central facilities as schools, fire stations, and retail stores (Ghosh and Rushton, 1987). Other researchers were concerned with the optimal design of voting districts or the optimal routing of power lines or roads across terrain.