Report

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Integration of ortho-images in GIS

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ABSTRACT

Digital ortho-images provide great advantages in comparison to their analogue counterparts, especially with respect to flexibility, production of derived products and combination with other data sets. Today, production of digital ortho-images has become more operational due to the development of more powerful computers with sufficient resources, easier acquisition of input data, increased generation of digital data, development of many commercial ortho-image production systems, and new application areas, particularly in connection to GIS and digital mapping. Different aspects of integration of ortho-images in GIS and the related requirements will be addressed. The paper focusses on the different extensions and possible uses of ortho-images in a GIS. Today digital ortho-images are primarily used either for visualisation or as a backdrop. However, ortho-images offer many, to a large extent unexploited possibilities, especially for the update of digital maps, automated mapping, and the generation of new data bases. Different modes for the extraction of 3-D information and object classification are presented. The paper concludes with an outline of future trends in research and development.

1. INTRODUCTION

Ortho-images and ortho-image maps are becoming increasingly popular products. They are easy to produce and they constitute an inexpensive substitute and addition to topographic maps, especially when the latter are not easy to produce or update. Ortho-image maps include a wealth of pictorial information and essential vectorial information in implicit or explicit form as well. Digital ortho-image production techniques offer an enormous flexibility and a high throughput at low cost, without the image quality degradation of the analogue techniques (losses of accuracy and resolution, difficult mosaicking, especially for colour images). Digital ortho-images are stable, their radiometry can be easily manipulated, and their accuracy, especially the relative accuracy, can be very high. Although digital ortho-images can be produced faster and cheaper than analogue ones, their main advantage is that they lead to new possibilities and applications. The most important of them is the integration of digital ortho-images in GIS. Furthermore, digital ortho-images allow the generation of many derived products (e.g. for visualisation) and combination with other data sets, and pave the way for automated image analysis and digital mapping. The main disadvantages of digital ortho-image production are the expensive I/O devices (especially plotters) and the big data sets with the associated requirements of CPU power, RAM, disk capacity and archiving. Another problem, important especially for large-scale applications, is the fact that DTMs do not provide full 3-D information and thus, all 3-D objects on the terrain are distorted in the ortho-images. The most important aspects regarding ortho-images are: (a) the geometric accuracy (which is primarily a function of the image scale, ortho-image scale and DTM quality), (b) the resolution, (c) the scale, and (d) the radiometric quality.

Today, digital ortho-images have become very popular for many reasons. About 30 companies offer systems and S/W modules for digital ortho-image generation (some of them include only rectification by polynomials, others offer additional packages for automatic DTM generation). There is an abundance of companies that offer digital ortho-image generation as service, very often within larger GIS projects. Last year ASPRS made a market survey on digital ortho-images involving ca. 90 companies. Different systems have been developed within the academic community. Public and other organisations around the world recognise the value of digital ortho-images and integrate or plan to integrate them in their production (USGS, USA TEC, State Offices of Surveying in F.R.Germany, Belgium, Netherlands, New Zealand, Cartographic Institute of Catalonia).

Digital data are becoming increasingly available from remote sensing systems, and video-based aerial photography. Organisations like ESA, SPOT Image and EOSAT offer value-added products, the most important of which are geocoded or even ortho-rectified ERS-1 SAR, SPOT and Landsat TM images. SPOT Image and EOSAT offer GIS-compatible products, like SPOTView and TM MicroScene, that can be directly imported in Arc/Info and with frame sizes that fit the standard USGS maps. The abundance of data and their combined use and analysis lead to the need for a common geographic reference. The latter requirement is automatically fulfilled by ortho-images.

Many applications require the coverage of large areas in short time or in short periodic time intervals. Typical examples include environmental monitoring, natural hazards, resource management, change detection, planning etc.. Ortho-images constitute the ideal product for such applications.

The acquisition of the input data that are necessary for ortho-image generation has become easier. Today, relatively low-cost DTP scanners offer scanning of transparencies up to A3 format at 600-1200 dpi true optical resolution. These scanners typically exhibit large geometric errors due to lens distortion, imprecise stage movement and positioning, and vibrations, but with a careful calibration a geometric accuracy of less than 0.5 pixel RMS can be achieved. It is expected that their price will drop and their performance will improve. DTM data are becoming a standard product of mapping organisations. SPOT DTMs are offered by SPOT Image and private companies. Automatic DTM generation is feasible for small and medium scales and will soon be fully operational. Acquisition of control has become easier through the use of GPS.

Digital ortho-images will be boosted by the developments in digital mapping. Once digital maps exist, it is a natural step to combine them with ortho-images and other information to derive new products, or to use ortho-images for their updating. The requirements of actual, precise maps at the time, scale, region and with the information the users wish, cannot be fulfilled with the traditional topographic maps. Digital ortho-image maps can successfully supplement or replace them.

2. ASPECTS OF ORTHO-IMAGE INTEGRATION IN GIS AND STANDARDS

There are different aspects of the integration of ortho-images in GIS, some of which will be briefly discussed. Most of them are common for the integration of any raster data, and in particular DTMs, in GIS.

There are different image formats and there is no hope that a standard will emerge soon. The selection of a format, or the development of a new one, is not that critical if it fulfils certain requirements and conversion to other formats is possible. However, duplication of data, and time- and disk-consuming conversions can be avoided by selection of a widely used format, particularly in I/O devices, like TIFF. Some of the requirements on the image format include:

- Complete header information

  The header should contain the whole history of the ortho-image creation, be expandable, and preferably be in ASCII format. The information should be complete to allow derivation of all necessary information. As an example, information on the exterior, and interior orientation of the photograph from which the ortho-image was generated, lens distortion or additional parameters modelling systematic errors, and the transformation from photo to pixel (of the scanned raw data) coordinates, including correction values from the scanner calibration, allow derivation of photo and pixel coordinates for any ortho-image pixel, generation of digital images in the photo or scanner coordinate system with sufficient completeness, and in the case of ortho-images of stereo pairs, measurement of 3-D coordinates.

- Tiling

  Large data sets can not be kept entirely in RAM. Sequential formats (whether B/W, BIL, BIP or BIB) do not permit a fast retrieval of data within a small neighbourhood, operation which is required in most image processing operations. Images divided in tiles of variable size can cope with this problem.

- Image compression

  To reduce the storage requirements image compression should be used (even destructive compression techniques could come into question, if the advantages outweigh the losses). With the emergence of the JPEG standard and commercial compression/decompression boards this possibility can be easily realised with very fast time responses.

Data structures and data base management of ortho-images should be addressed. There is apparently no unique optimal solution to this topic, as it strongly depends on the nature and capabilities of GIS, the applications, and the required data types and sizes. Ortho-images can be stored and managed in a data base in different modes: (a) together with all other raster data, (b) together with all other geocoded raster data (for certain applications an ortho-image can even be combined with the corresponding DTM in a single file), whereby other type of images (e.g. single images, video sequences) can be treated as attributes of objects, or (c) in an integrated data base including all GIS data. The latter option seems theoretically appealing, but has to deal with problems like large data sets, different nature and representation of data, complicated data structures, and long retrieval times.

Another aspect is the relation of the ortho-image generation system to GIS. Although digital ortho-images will soon be widely offered as a standard product, GIS users may occasionally need the capability to create their own ortho-images. Also large producers of ortho-images must consider what is the optimal production configuration. There are two main possibilities:

- Generation by a system that is independent from GIS

  This option can be subdivided in two cases: (a) large, and (b) small production. In the first, powerful dedicated ortho-image production workstations, closely coupled with image scanners (or other workstations driving the scanners) seem to be the appropriate solution. Editing and validation of ortho-images might be performed on a separate workstation. In the second case the ortho-image generation S/W will typically run on the same hardware platform and under the same window system as the GIS. In both cases data transfer through a local network and data reformatting might be required.

- Ortho-image S/W module within the GIS (e.g. Intergraph, Erdas)

  In this case, some of the functions that are required for ortho-image generation typically already exist in the GIS.

With the integration of ortho-images, GIS systems should offer the necessary functionality for their display, handling and manipulation. The requirements are similar as with digital photogrammetric stations. Display functions (pan, scroll, zoom in/out, overview) should be fast and comfortable. Display and subpixel measurement in mono and, for some applications stereo, mode is required. Other necessary functions include: raster editor, image processing, graphics support, map composing for generation of ortho-image maps. For measurements, a direct combination with a DTM and on-the-fly 3-D vector digitisation of terrain features, as well as semi-automated image analysis techniques for feature extraction should be supported.

To ensure an easy exchange and high quality of the data, standards are required with respect to:

- production (I/O data, data acquisition, processing)
- quality control

- data formats
- distribution and archival media

Of particular importance is the assurance of high quality. Without this prerequisite, time, effort and money will be spent for a poor outcome, the wide use of ortho-images will be undermined, and new low quality data will be, mostly unintentionally, generated by extraction from the ortho-images. High standards are particularly required for large projects, especially if the production and usage of ortho-images is performed cooperatively by many organisations. In this respect, the USGS National Mapping Division standards for digital orthophotos (*USGS*, *1992*) have certain weaknesses. They will be addressed here because this topic is of general importance. Some serious weaknesses include:

- Geometric accuracy validation

  Firstly, the National Mapping Accuracy Standards (NMAS) require that only 90% of the tested points must be within specifications. The remaining 10% can even be huge blunders. It is clear that all points should be included in the derivation of an RMS error, while an upper bound on the maximum absolute error and/or a maximum percentage of points that are above a threshold (considered to be blunders) are also required to guarantee a minimum geometric accuracy. The accuracy requirements of 12 m and 10 m for the ortho-image quadrangles and quarter quadrangles respectively seem to be low. Such accuracies, or even better, can be achieved using SPOT ortho-images from 1:800,000 scale imagery. With the B/H ratio of 0.6 for the National Aerial Photography Program (NAPP) imagery and an RMS elevation error of no greater than 7 m, a planimetric accuracy of ca. 4 m can be achieved and should be required. Today, the increased accuracy demands of the users and the high accuracy potential of the ortho-images should lead to the formulation of more stringent and better defined standards, than the NMAS. The minimum number of test points is only 4, while no requirement is placed on their covering the whole image format and the whole elevation range sufficiently. The coordinates of the test points should be compared to data of higher-order accuracy without any further specification as to what this order should be. It is clear that the main obstacle to a comprehensive and trustworthy accuracy test is the acquisition of sufficient, and accurate control. By using ortho-images of stereo-pairs and the approach explained in section 3.2, X, Y, Z coordinates of several well-defined points could be determined easily with semi- or fully automated procedures with the same accuracy that new points can be determined by using measurements in the raw images. Thus, sufficient control could be established in conjunction with the ortho-image generation process, quickly and with low cost, and could be used to check not only the ortho-image but also the underlying DTM accuracy.

- Production specifications

  For the remaining input data and processes only wishes for sufficient accuracy are expressed. An alternative would be to specify maximum errors for the aerotriangulation control, possibly the method to estimate the exterior orientation of the images (e.g. space resection may lead to geometric inconsistencies of neighbouring ortho-images in the mosaicking phase, while a bundle block adjustment with sufficient tie and pass points would lead to a much better fit), and specifications for the scanner (maximum RMS geometric errors, radiometric quality and dynamic range etc.). Additionally, it should be specified if, and when, to use corrections for earth curvature, atmospheric refraction and lens distortion. Correction measures must be specified in the case that there is a geometric misregistration between neighbouring ortho-images.

- Image format

  The header does not include useful information on camera orientation, and scanner calibration, as explained previously. Additionally, tiling and compressed data are not supported, nor is any plan for their future support stated.

- Distribution and archival media

  The standard medium is nine-track magnetic tapes. There are many obvious reasons involving costs, storage space, capacity, medium stability, future improvement etc. why video-8 tapes and CD-ROMs (or the less widely used DATs) should be preferred. At this point the following remark (*Skalet et al., 1992*) from USGS staff suffices: “Storage of orthophotos for the conterminous United States would require at least 120,000 tapes. The same data could be stored on 2,700 8-mm digital audio tapes”.

3. EXTENSIONS OF ORTHO-IMAGES AND 3-D INFORMATION EXTRACTION

The usage of mono B/W ortho-images can be extended by different options.

3.1. Colour ortho-images

This option is useful for multispectral analysis, visualisation and animation, and improved manual feature classification. If the spectral channels are well co-registered, then a multispectral ortho-image can be produced at relatively low additional computing costs in comparison to a single channel ortho-image. The extra requirements include the reading of the input images, writing of the ortho-image channels, and grey level interpolation, whereby the coefficients for the interpolation must be computed only once. Accuracy control needs to be performed only for one channel. However, the storage and computing power requirements increase to a considerable extent, radiometric adjustment during mosaicking becomes more complicated, hardcopy output more expensive and time consuming. Thus, colour ortho-image production for large countries does not seem to be realistic today.

3.2. Orthorectified stereo images

Two ortho-images of the same region (DTM) from each of the images of a stereo pair can be created. The use of such an ortho-image pair (orthorectified stereo images) can serve several purposes.

- Measurement of 3-D coordinates

  Correct X, Y, Z measurements can be made, even if the underlying DTM is totally incorrect. The procedure is the following. The point to be measured is selected in one of the images with the cursor, and measured in the second image either manually, or even better by image matching, if there is sufficient texture. The search for the corresponding point is minimal, since corresponding points should ideally have the same pixel coordinates. The small time difference between acquisition of the two images ensures that in almost all cases corresponding points will have a similar appearance in both images. Corresponding points in the two ortho-images are measured, the pixel coordinates are transformed to planimetric coordinates and the height is interpolated from the DTM. These two X, Y, Z values can be transformed into photo coordinates, if the appropriate information is stored in the image header as explained previously. Through ray intersection, correct X, Y, Z coordinates can be computed, even if the starting DTM elevations are wrong. These measurements are as accurate as measurements in the original unrectified images, if the ortho-image pixel size is not larger than the scanning pixel size. This is natural because the two measurement processes use the same information. However, measuring directly in the ortho-images is not only conceptually superior since it occurs in the object space directly, and overlay of vector or other raster geocoded information is much easier; it also permits easy and fast measurement of corresponding points either automatically or manually, in the latter case without the need to resample along epipolar lines as with unrectified images.

  This procedure can be used in particular for DTM correction, measurement of 3-D objects that are not included in the DTM, and easy establishment of many control points to check the ortho-image accuracy. After the above procedures have been completed, one of the two ortho-images can be deleted to decrease the storage requirements, and further 3-D measurements can be performed using the corrected ortho-image, DTM, and digitised outline of the top surface of 3-D objects.

- Establishment of control for geometric accuracy validation of ortho-images

  In principle the procedure to be followed was outlined above. Additionally, the selection of the points in the first image can be performed by an interest operator, so that well-defined points, e.g. nearly rectangular corners, are selected. Thus, the whole quality control can be fully automated and hundreds of control points, covering the whole image, can be measured. However, this is not necessary if the DTM is corrected as explained below.

- Detection and correction of DTM errors

  If the exposure of the images occurred with a small time difference, and the errors due to sensor modelling, photo to scanner transformation, and scanner geometry and radiometric instabilities are small (which will be the case if the necessary precautions are taken), then the two ortho-images will be perfectly co-registered (zero parallax) and the grey values at corresponding positions will be very similar except at places where:

  (i) the DTM is correct but there are radiometric differences between the two unrectified images due to (a) differences in viewing angle, noise, illumination, (b) occlusions, or (c) inclined (non-vertical) surface faces with a very different extent in the two images

  (ii) there are 3-D objects (houses, trees etc.) not modelled by the DTM, or

  (iii) the DTM is incorrect

  Positions of such differences can be detected either by manual stereoscopic observation (they would appear as deviations from an otherwise flat plane) or by semi-automated procedures. The latter include matching a grid of points of the left ortho-image in the right one, whereas the mismatches will indicate the above problematic cases. Instead of matching at all grid nodes, candidate mismatches could be detected by a radiometric equalisation of the two images and subsequent subtraction of the images. Matching in ortho-images becomes easier because scale and shear differences are small, the shift is primarily in the x-direction, and the search space is small, i.e. the approximations are good. The case of 3-D objects (case (ii)) does not refer to the DTM and will be treated later. In case (iii), the parallaxes can be determined by matching except in cases of radiometric distortions as listed under (i), where manual measurement is required. Manually and automatically measured parallaxes can be transformed in elevation errors and thus correct elevations can be computed at points that usually fall between the DTM nodes. To find the elevation at the DTM nodes, either the elevation errors must be approximately transferred at the DTM nodes, and the matching procedure and elevation correction must be repeated until the latter falls below a threshold, or the elevation at the nodes must be interpolated from corrected, arbitrarily distributed neighbours. The latter approach is faster and more accurate, the first one has been applied by *Norvelle, 1992*. After each DTM correction, the ortho-image regions that are influenced by the corrections must be recomputed.

  With this procedure, the ortho-image does not simply use the DTM; the former is also used to correct the latter. *Light, 1993* gives the NAPP planimetric and height accuracy as 0.4 m and 0.7 m respectively in case of analytical triangulation, while the practical map accuracy depends on the stereoplotting instrument employed and is typically 0.8 m and 1.1 m respectively. Even in the latter case, the accuracy that can be achieved is much better than the original DTM accuracy. Thus, in one step the DTM can be improved as well as the planimetric accuracy of the ortho-image which depends a lot on the DTM quality.

Figure 1. Ortho-image: (left) houses are radially displaced, (right) the houses indicated by the arrows are corrected a posteriori.

- Measurement and correct representation of 3-D objects

  In ortho-images 3-D objects are displaced radially from the nadir, because there are not included in the DTM. There are more and more applications where such objects (especially buildings and elevated road structures) must be correctly represented either because they are of interest themselves, or because they otherwise hide other useful information. Such large-scale applications are becoming a big market. Automatic DTM generation by image matching should theoretically measure the visible surface, so DTMs derived by these means could be used in the ortho-image generation. However, in large-scale urban scenes, matching algorithms generally have a poor performance caused by discontinuities, occlusions, shadows and large perspective differences. In this respect, a combination of area- and edge-based matching techniques could lead to a significant improvement. Even in this case, if a DTM must be subsequently interpolated from arbitrarily distributed points by one of the commercially available packages, problems could arise because most of them can not treat vertical surfaces. For all these reasons, a viable alternative is to measure the top surface of 3-D objects and either combine this information with the DTMs before ortho-image generation, or apply a posteriori corrections to the ortho-images. The latter approach is attractive because the measurement can occur in orthorectified stereo pairs as explained above.

  Figure 1 shows an example before and after correction. The difference in area between displaced and orthorectified object surface gives the pixels which are occluded by the object and must be newly determined by using grey values from other images (this has not been performed in Figure 1). Other examples of such corrections are given in *Behr, 1989*.

  A next step would be a full 3-D description of the objects (not only measurement of their top surface). This can be partially made under certain assumptions and conditions that permit an estimation of the nonvisible parts of the objects, or by using neighbouring images where these occlusions are visible. For a detailed and complete description, however, terrestrial images or surveying techniques might be inevitable. An additional problem is that today 3-D object models can not be handled in GIS (but they can in CAD systems), and that the choice of an appropriate modelling is object/application dependent, e.g. in geology volumetric models are widely used while in architecture models are based on nodes, lines and planes.

3.3. Stereo ortho-images (stereomates)

A stereomate can be produced during the ortho-image generation at low additional cost. Horizontal parallaxes are computed as a function of the elevation for all DTM nodes, linearly interpolated for each ortho-image pixel, a 1-D grey level interpolation (typically linear) for each pixel of the stereomate is performed, and the image saved on disk. A problem is the lack of pixel information on the vertical faces of 3-D objects (e.g. buildings), if the radial displacements of these objects have been corrected as explained in section 3.2. This information can be either taken from the unrectified images, or filled-in synthetically. Actually, all GIS that support drapping of ortho-images on 3-D wire models of the terrain with the view placed at infinity can create a stereomate by just selecting a oblique parallel view of the texture-mapped terrain. However, this way of stereomate generation is computationally not optimal, and the accuracy and rigour of the drapping computations is usually unknown. The stereomate can be either saved permanently, or generated on-line for a provisional use and then deleted. Stereomates have several advantages. They permit a better feature recognition, and allow derivation of heights (without the need for the underlying DTM). 3-D stereo measurements and mapping can be performed. With the aid of a DTM, vector information overlaid on the ortho-image can be also overlaid on the stereomate (and maybe even stored permanently), leading thus to stereo maps. Hardcopy stereo ortho-images and ortho-image maps can be easily used by many environmental scientists (e.g. geologists, foresters) in the field for completion and checking. The relatively old, but still very current and forward thinking publication of *Blachut, 1971* gives useful details on the theory of stereo ortho-images, and possible applications, although it describes an analogue stereo ortho-image system.

3.4. Feature extraction by use of image analysis techniques

Semi-automated feature extraction can be performed either on mono or stereo ortho-images. Research efforts have concentrated on

- pattern classification by using multispectral, textural, DTM, context and other available information, especially for landcover and landuse determination.
- extraction of linear features like roads and rivers, boundaries of landcover zones (fields, forests, lakes, coast lines), buildings and other manmade structures.

The existence of a priori knowledge in GIS can be favourably exploited in the direction of knowledge- and model-based object recognition. Unfortunately, there is a gap between computer vision scientists and GIS users and the development of “GIS-based image analysis” will be a very slow process. There is a long way to go until fully operational and automated feature extraction is accomplished, but even today the image analysis techniques can support the operator for a faster, more comfortable and more accurate digitisation. At our Institute we are currently working on road extraction, and linear feature extraction using active contour models (*Fua and Leclerc, 1988*) and least-squares matching adapted to edge detection (*Gruen and Stallmann, 1992*). Figure 2 shows the raw measurements of the latter method.

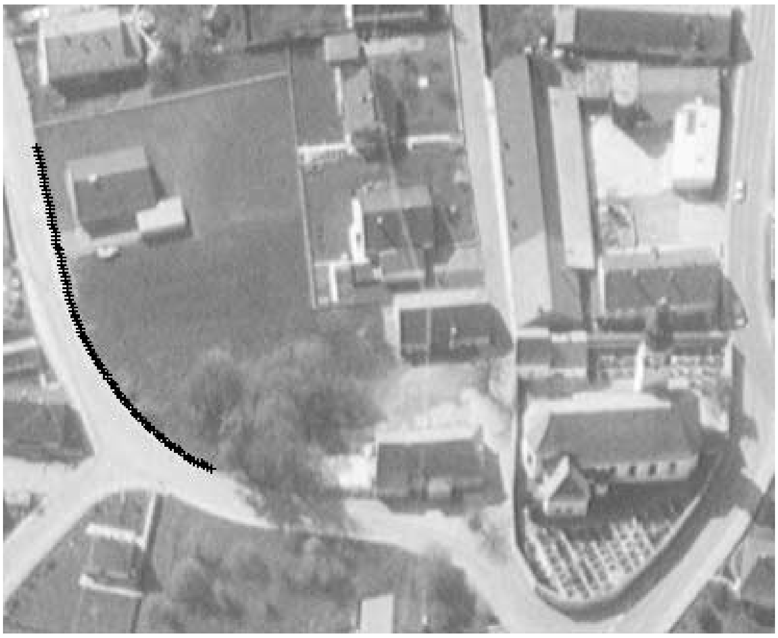

Figure 2. Semi-automated feature extraction. Black crosses show detected edge points along the road.

4. USAGE OF ORTHO-IMAGES IN GIS

The usefulness of ortho-images in a GIS goes far beyond the establishment and the archival of a data base, and the usage as a backdrop for presentation of other data or digitisation. Applications of ortho-images in a GIS include:

- Data quality control through overlaying

  Correction of vector or other raster data, quality control of the ortho-image geometric accuracy.

- Drapping of ortho-images, and other vector and raster data on DTMs

  Creation of texture-mapped 3-D views, generation of sequences, animation, simulation (particularly for planning purposes).

- Generation of ortho-image maps

  Fast and cheap map generation, description of up-to-date information, easily interpretable, little cartographic symbolisation required (often used with satellite and especially SPOT images). Overlaying on ortho-images of raster maps (or layers thereof) for navigation or other purposes.

- Processing and analysis

  Statistic functions, boolean operations, neighbourhood and connectivity analysis (raster data particularly suitable for analysis of large extent, continuous phenomena).

- Combination with other image data (data fusion, integrated sensor systems)

  E.g. SPOT and TM (for good geometric and spectral information respectively), SPOT and SAR (easier interpretation of SAR images, cloud covered areas in SPOT replaced by SAR), simpler and more accurate image to map registration through registration of the image to an ortho-image of the region.

- Improvement of multispectral or other classification techniques

Combination with other existing geocoded information (DTMs and derived products like slope maps, texture-based segmentation, thematic layers like geology and vegetation), use of ground truth data that often exist in a GIS for an easy choice of training regions, and classification accuracy analysis.

- Intersection with other data

  (i) raster data (DTMs, classification images), (ii) vector data (polygons, lines, points, e.g. parcel boundaries, middle axes of roads, oil wells), and (iii) attribute data

- Change detection applications

  These applications are becoming increasingly important. Since DTMs remain relatively stable, creation of new ortho-images and comparison to older ones can be easily made. Regions of changes can thus be highlighted, possibly in combination with other GIS information, e.g. change of the population, road network etc.. Overlay of old features in these regions on the ortho-image can lead to formulation of hypotheses (e.g. all old features still exist) and their verification or rejection can be based on criteria derived from the ortho-image signal by application of semi-automated feature extraction and classification techniques that make use of all pre-existing knowledge.

- Ortho-images as national land basemap

  Today, GIS land base information is often created by different methods, e.g. photogrammetry and digitisation of cadastral plans, and often has different data, as they were specified by the user. Such problems, and overlapping, independent activities can be avoided, if ortho-images are used as a common land base, whereby many users share the costs but each user maintains his own thematic layers . Lower resolution ortho-images can be easily created by use of image pyramids (inherent and simple generalisation of the pictorial information).

- DTM quality control (see section 3.2)
- Generation of new data bases

  Many possibilities have been discussed in section 3 (mono ortho-image with or without DTM, stereo ortho-images, orthorectified stereo pairs). In many cases ortho-images provide an easy and cheap entry level into GIS.

- Data update

  Particularly important is the update of digital maps. Digitised maps are older and in most of the cases less precise than current ortho-images. Map update is sometimes performed by a completely new mapping (expensive solution, inconsistencies in feature location may arise due to new compilation). Update of selective data will in many cases be performed by the GIS user himself, as the update cycles of typically 5-10 years are too long.

Summarising, for geometric and semantic information extraction different modes may be used:

1. mono ortho-images

   With a DTM, map coordinates can be derived only for objects on the terrain. There are problems with the identification and classification, especially in forested and urban areas. Identification/classification can be improved by using a larger image scale, better quality scan originals, smaller scan and ortho-image pixel size, colour, and image enhancement techniques.

2. a) orthorectified stereo pairs

   For any ortho-image point, even if its DTM elevation is erroneous, correct X,Y, Z coordinates can be derived with an accuracy similar to the accuracy of measurements in the unrectified stereo pair. DTM errors can be detected and corrected, accurate control can be established for the ortho-image geometric accuracy validation, visible points on 3-D objects that are not included in the DTM can be measured, and the ortho-image can be reproduced at a better quality with the corrected DTM. Stereo viewing leads to a flat surface, and thus interpretation capabilities are the same as with mono ortho-images.

b) stereo ortho-images

Easy and fast generation, elevations can be measured even without a DTM, optimal stereo viewing without y-parallax and radiometric differences, no correction of DTM or ortho-image errors possible (not necessary if step 2 a) is performed first).

3. mono unrectified images

   Mapping possible only with a DTM (at higher complexity and time requirements than for mono ortho-images).

4. stereo unrectified images

   High accuracy and full 3-D measurement capability. Stereoviewing requires epipolar transformation of one of the images.

From all modes involving ortho-images, the mono option is the simplest, fastest, cheapest, requiring less data, and being supported by many H/W and S/W platforms. The options based on unrectified images, require 3-D information for overlaying of vectors (their elevations, or a DTM, the latter is applicable only for terrain features). Ortho-images, on the contrary, can be overlaid with any geocoded vector or raster information.

5. FUTURE DEVELOPMENTS AND TRENDS

Digital ortho-images will be widely used in the near future. H/W and S/W developments will make their production simpler, faster, and cheaper. Other parallel developments, like the operationalisation of automatic DTM generation, and the combination with GPS (reduction of control, measurement of control with GPS, precise navigation) which will make the time-consuming aerial triangulation easier or redundant, will enhance the attractivity of digital ortho-images. Multispectral ortho-images will gain in importance. Ortho-images will be produced in all scales, and increasingly in large-scales, not only because of the requirements of important GIS-users like city authorities, utilities etc., but also because data updating is more crucial in these scales. For measurement and interpretation any possible configuration (mono, or stereo ortho-images, orthorectified stereo pairs, mono or stereo unrectified images, or even use of more than two images) may be used depending on the application and the available resources.

Digital ortho-image generation systems will be complete, mature, fully integrated end-to-end systems, using off-the-shelf hardware, and supporting high-precision ortho-image generation from practically all useful sensors. Stereoviewing capabilities will be a default. Ortho-image generation can occur either in a GIS or with a separate system. On one hand, general purpose GIS will mostly have modules for image processing and analysis, remote sensing, photogrammetry, computer graphics, and visualisation. However, a universal system that can do everything should not be expected. “Vector-based” GIS can evolve into such general purpose systems easier than “raster-based” GIS. The photogrammetric data acquisition will eventually be also integrated in some GIS, maybe as a blackbox. On the other hand, special purpose GIS will exist and be developed in parallel to the general purpose ones. These “dedicated” GIS might have their own data, data structures, algorithms etc., all tailored and optimised for specific applications.

Digital ortho-images will support/replace the conventional maps. Custom-made maps will be offered as a standard service, whereby the user will be able to specify the coverage area, the scale, the type of information in the map, the type of the output (soft- or hardcopy), or even the way of the representation (line map, ortho-image map, 3-D view, video sequence). The conventional maps will stay for a long time, but only as a byproduct.

Ortho-images will be fully integrated in GIS. No flexible, general purpose GIS can exist without the integration of ortho-images and other raster data. This will lead to really hybrid, integrated GIS, where the integration covers all aspects (data bases, processing and analysis algorithms, graphics/ visualisation, even I/O). Raster data will be at least as valuable as vector data.

The aspect “time” will become more important in GIS. Data are information today, but not tomorrow! Ortho-images are a tool for fast information acquisition and updating. Real-time applications will come in the foreground (real-time mapping) and ortho-images will be generated on-the-fly.

Advances in image analysis will permit the extraction of geometric and semantic information for a variety of objects. Developments in object representation and modelling will go hand-in-hand with the development of 3-D, object oriented GIS, whereby representation, methods, and data will all be object dependent.

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