GENERATING AND UPDATING SPATIAL DATABASES BY USING MONO- AND STEREO-DIGITAL ORTHOIMAGES

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Abstract

Today, production of digital orthoimages has become more commonplace 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 orthoimage production systems, and new application areas, particularly in connection to GIS and digital mapping. The increasing importance of orthoimages is also indicated by many orthoimage generation projects on national, regional and local levels, and the use of orthoimages as basemap layer within GIS. The paper presents different applications on generating and updating of spatial databases using mono- and stereo- orthoimages. Used methodology and some results from ongoing projects at the ETH and the Canada Centre for Topographic Information (CCTI) will be outlined. The applications include map updating using mono orthoimages, building extraction from aerial images, and change detection. In addition, the methodology for extracting 3D information from orthoimages of a stereo pair and possible uses of this method are explained.

1. Introduction

The paper structure is as follows. In Section 2 a pilot project at CCTI on revision of 1:50 000 topographic maps using mono orthoimages and heads-up digitising is presented. Section 3 outlines the concept of making accurate 3D measurements using orthorectified stereo pairs, even if the Digital Terrain Model (DTM) used for their generation was erroneous. Section 4 and Section 5 present methods that are on a research level, and more specifically on the use of orthoimages (mono and stereo) for modelling of buildings, feature extraction and change detection.

2. Revision of 1:50 000 map data using mono orthoimages and heads-up digitising

2.1 Methodology

CCTI is responsible for the production and maintenance of the National Topographic Series (NTS) maps for Canada at scales 1:50 000 and 1:250 000. The implementation of new technology has been a continuous commitment at CCTI. A strategy to implement fully digital workflow is in progress as the use of modern technology for automating production aiming at cost reduction, faster turnaround time, more flexible products, and client satisfaction is very important. With the acquisition of digital photogrammetric workstations, CCTI is implementing modern digital technology for map compilation and revision, and quality control.

An investigation was performed to evaluate the potential of updating the 1:50 000 Jasper topographic map from digital orthoimages. The map data was scanned and then vectorized. New aerial photography at scale of 1:60 000 was acquired to revise the "old" map data. Map revision operations for existing vector data from aerial photographs require the following steps:

- change detection
- collection of new data (feature extraction)
- photo-interpretation (feature classification)
- integration of old and new data in the database

One of the effective methods for the extraction of new data is by the superimposition of the existing "old" digital vector data over digitized "new" aerial photography. If the image is orthorectified, then the updating of the database is performed by collecting the new information from the image. In our application, the updating of the vector map data was performed using the digital mono-orthocompilation technique, that is the on-screen digitisation of planimetric details from digital orthoimage mosaics displayed as a backdrop to the 1:50 000 digital data [10]. Other reports on the use of orthoimages for map generation and updating are given in [2, 12]. Figure 1 shows the work flow. Attribute changes in the data are applied based on information collected during the field work. The height information of the planimetric features can be derived from the DTM used to produce the orthoimages either in real-time or in post-processing mode. For this map revision the existing metric contours were edited and maintained

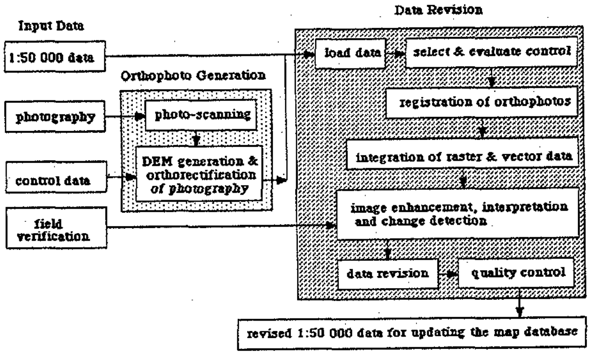


Figure 1 Data flow for the revision of 1:50000 map data using digital orthoimages.

2.2. System requirements

To meet the production requirements of the selected methodology of revising 1:50 000 data, the systems used must offer certain functionality, such as: generation of digital images by scanning diapositives of aerial photographs, production of digital orthoimages and mosaics from existing DTM or by generating the DTM from the newly digitized photographs using image matching techniques, image processing functions, integration of vector and raster data capabilities, topology creation and cartographic editing. These capabilities are found in the digital photogrammetric workstations and in vector-raster GIS.

For the production of the digital orthoimage mosaics for the revision of the Jasper map data, the Leica/Helava DSW 100 system was used for the scanning of the photo-diapositives and the Leica/Helava DPW770 was used for the production of the digital orthoimage mosaics. For the actual revision operation from the digital orthoimage mosaics the CARIS GIS - a vector-based topographic mapping and GIS system integrated with raster data handling capability - was used. Several aspects on the integration of digital orthoimages in GIS have been addressed in [3]

2.3. *Digital orthoimage mosaics*

The area covered by the Jasper map sheet is 32 x 26 km^2. The task involved scanning 25 aerial photos flown at a scale of 1:60 000. When scanned at 1000 dpi the resultant pixel size was 1.5 m. The DTM was computed on a 50 m grid which resulted in 332.800 elevation posts with an estimated RMS of 1.5 m. The orthoimages mosaic was resampled with the nearest neighbour method with an output pixel size of 2 m ground resolution. Due to the large size of the mosaicked raster file (about 240 Mbytes) the sheet was divided into four orthoimage quads with each quad being a more manageable 70 Mbytes. This size of a quad seems to be the optimum size of raster file for the various operations (e.g. display, panning and zooming).

2.4. *Georeference of the orthoimage mosaics on the CARIS GIS*

The four orthoimage quads were exported via the network from the Helava system in TIFF format to the CARIS GIS system, and reformatted to CARIS raster IPV readable format. The reformatted TIFF files maintain the raster row and column dimensions and the orientation of the data, but the origin and the pixel size are in internal CARIS disk units. Therefore, the digital orthoimage mosaics must be re-georeferenced from the CARIS coordinate system to the UTM system. Since the orthoimage mosaic lost its georeferencing due to the format changes, the re-georeferencing of the orthoimage mosaic is done using the "one-point anchor" method. This is accomplished using one reference point - the lower left pixel of the orthoimage quad in this case - by a translation in x- and y-directions and rescaling along these two directions using the actual ground pixel size and the image dimensions. It should be noted that no additional resampling is required in this georeferencing approach.

Following the re-georeferencing, an evaluation of the metric accuracy of the registered orthoimage mosaics is performed by measurement of the coordinates of the check points from the orthoimage mosaic and comparing them with the given values from the aerotriangulation. For the four quads used for the revision of the Jasper data, the standard deviation of the differences were from ±1.17 to ±1.67 m in x and from ±1.50 to ±2.69 m in y, which well satisfied the NATO A rating planimetric accuracy requirements for 1:50 000 maps.

2.5. *Revision of the map vector data*

The orthoimage quads were displayed one at a time and the CARIS file manager utility was used to integrate the raster and vector data to facilitate the use of superimposition for the collection of the new data. For the revised data, a date stamp was fixed by setting the source id to "REV94". This enabled the revision operator to identify all the features that have been revised and separate them from the original data for quality control. The cartographic editing operator may also make use of this attribute to identify the data requiring cartographic editing.

The criteria for feature revision or recompilation were based on the following factors:

- the amount of change detected (spatial and semantic)
- the accuracy of the existing feature
- the topology
- the significance of the feature

The task of change detection was performed visually by displaying the superimposed vector and raster files to determine areas within the vector file that have changed. This was aided by relying on the field verification photo-prints for classification of roads, and noted additions, deletions and changes of features.

Updating and recompilation of the planimetric map data was performed using heads-up digitizing. The menus of the CARIS-based Cartographic Editing System (CES. [6]) facilitated the revision of features without having to type-in edit commands and feature codes. A tile approach was used for the revision process. where the operator steps through the data set in small virtual map tiles. revising all the features before moving to the next tile. Also use of the zoom in/out capabilities were applied for data collection. During revision the selective display of features was applied for best results. In conjunction with the display on screen. the operator used a stereoscope and air photography with field information to view the area's relief. identify features such as watercourse and permanent snow and ice (glaciers) and collect them with greater ease. Figure 2 shows the "old" and the revised "new" vector data of the Athabasca River features.

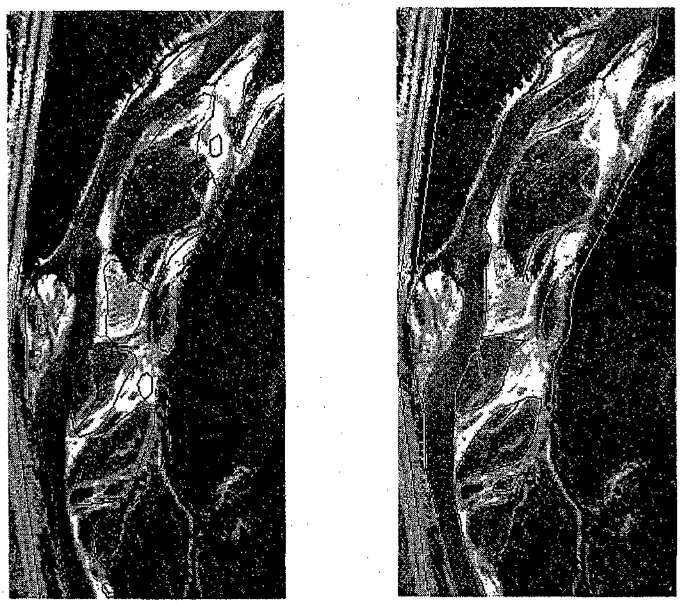


Figure 2. Old (left) and revised (right) vector data of the Athabasca River features.

The quality of the vector map data when viewed superimposed to the raster image appeared poor in some areas. Pockets of incorrectly positioned data. likely arising from tabletop revisions. were located and recompiled to improve the quality of the map data. An example of this was the industrial park just outside the town of Jasper's built-up area. The features had been captured, but were not in the correct position, with errors in positioning in the order of 50 m. Other features that required correction in positioning were roads, streets and buildings that were shifted by more than the allowable cartographic tolerance. The utilization of a digital system accommodated not only the two principle actions of revision. that is addition and deletion, but also attribute changes and easy repositioning of features.

As there is overlap between data revision and cartographic editing. when doing this project the question arose regarding the degree of cartographic editing to be performed during data revision. "Should the features be collected in their true position or should they be cartographically displaced at time of data collection?" The data set for Jasper map sheet was vectorized cartographic data and required a slightly different approach for revision than a positional data set. When revising a positional data set, the exact positional data would be collected. In the case of the revision of a cartographic data set, features that were not positionally correct due to cartographic displacement are not corrected. Repositioning these features would only result in additional work at the cartographic editing stage. Thus, "correct" cartographic data is maintained and only the incorrect data is repositioned. Since the revision includes a degree of cartographic editing, the CES utility WYSIWYG was found very useful. The WYSIWYG capability allowed the operator to turn feature symbology on and view the feature with its cartographic representation. This was useful for judging whether the existing feature was within the cartographic tolerance and to collect the revisions respecting cartographic requirements. For example, a railroad that was positionally "incorrect", but cartographically acceptable as shown with the symbology displayed was not edited.

The existing contours were compared visually to the ones generated from the derived DTM used for the production of the digital orthoimages. This preliminary comparison showed that it was not necessary to replace them. The editing performed on the contours consisted only of adjustments for the re-entrance on revised streams, and changing the code from "contour approximate" to "contour" where the contour had previously been drawn over a glacier that no longer exists. Elsewhere the contours were not edited

2.6. *Time requirements*

The time breakdown required for the completion of the prototype revision of the 1:50 000 NTS Jasper map sheet has been estimated to be:

Task	Total days
Aerotriangulation (cross pugging, measurements, adjustment)	5
Production of orthoimage mosaics	10
Preparation	6
• system preparation	2
• importing and preparing vector data set	2
• importing and preparation of the digital orthoimage mosaics	2
Digital map revision (revision/tecompilation)	30
Quality control	4
Total	55

These numbers are specific of the Jasper map sheet and may vary depending on the relief of the terrain and the amount of revision required. Please note that the time for field work is not included.

3. Measurement of 3D coordinates using orthorectified stereo images

Two orthoimages of the same region (same DTM) from each of the images of a stereo pair can be created. The use of such an orthoimage pair (orthorectified stereo images) can serve several purposes, all of which are based on the ability to determine 3D coordinates using corresponding points in an orthorectified stereo pair. Correct X, Y, Z measurements can be made, even if the underlying DTM is totally incorrect. The procedure is the following (see Figure 3). The point to be measured (P′) is selected in one of the images with the cursor, and measured in the second image (P′′) either manually, or by image matching. The resulting pixel coordinates are transformed to planimetric coordinates (X′, Y′, and X′′, Y′′) and their heights (Z′, Z′′) are bilinearly interpolated from the DTM. These two sets of (X, Y, Z) values can be transformed into photo coordinates (x′, y′ and x′′, y′′), using the known interior and ex terior orientation. These two image points are corresponding points, if the transformation from the photo- in the pixel-coordinate system is accurate. Through intersection of the corresponding rays, and if the interior and exterior sensor orientation are known with sufficient accuracy, correct X, Y, Z coordinates (X_P, Y_P, Z_P) can be computed, even if the starting DTM elevations are wrong

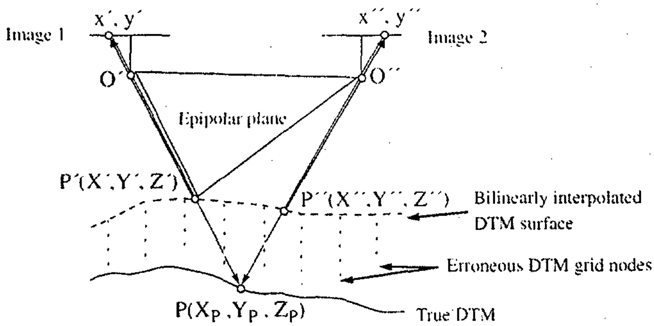


Figure 3. Determination of 3-D coordinates from homologous points P′, P″ in orthorectified stereo images.

The accuracy of object coordinate determination by the above method can be as high as the accuracy that can be achieved using the original unrectified digital images. To check the validity of the procedure a controlled test was performed. A 25 m grid reference DTM with an RMS error of ca. 2 m and two images of a relatively smooth terrain were used to create an orthorectified stereo pair. The images were scanned at 600 dpi with an Agfa Horizon, which has an RMS geometric error of 80 - 100 µm, and the control points were measured by GPS. The orthoimages had a pixel size of 1 m, corresponding approximately to the footprint of the raw image pixels. Twelve GPS points were also measured in the orthoimages. The resulting orthoimage planimetric accuracy was 2.5 m in X (Easting) and 4 m in Y (Northing) whereby the greater part of this error should be attributed to the scanner. The object coordinates of the GPS points were also computed from the orthorectified stereo pair by intersection and the heights were compared to the reference values leading to an RMS error of 3.5 m.

In addition, a subset of the DTM was selected, a constant error of 5 m, 25 m, and 50 m was introduced to this DTM, and orthorectified image pairs for the resulting 3 noise-corrupted DTMs and the original noise-free DTM were generated. 27 manually selected points were matched using least squares matching in all 8 orthoimages. From each of the four orthorectified stereo pairs the object coordinates were computed by intersection. These four sets of values are almost identical among each other (see Table 1), i.e. the coordinates computed by intersection are independent of the DTM errors. At the planimetric position of these object coordinates, the height was interpolated from the respective DTM (original DTM or with added noise) and these heights were compared to the heights estimated by the intersection (see Table 2). As it can be seen in Table 2 the errors for the noise-free DTM version and the errors for the noise-corrupted DTM versions differ almost exactly by the amount of the introduced errors. For the noise-free DTM the RMS difference is 4.7 m and similar to the 3.5 m RMS difference with the GPS coordinates. Summarising, the internal (relative) precision of the method is excellent : the absolute accuracy, assuming well calibrated cameras, depends on the accuracy of the matching results, the exterior orientation, and on the geometric accuracy of the scanner. Even with a scanner of poor geometric accu racy, like the one used in this test, DTM errors can be reduced to about 4 m.

Version	X (in m)		Y (in m)		Z (in m)	
	| Max |	RMS	| Max |	RMS	| Max |	RMS
(1) - (DTM + 5 m)	0.14	0.05	0.13	0.06	0.26	0.11
(1) - (DTM + 25 m)	0.12	0.05	0.20	0.09	0.38	0.15
(1) - (DTM + 50 m)	0.15	0.06	0.37	0.13	0.48	0.16

Table 1: Object coordinate differences between intersection results: (1) original DTM - (2) noise-corrupted DTMs

Version	Average	| Max |	RMS
DTM, no bias	0	2.58	1.17
DTM	-4.53	7.11	4.68
DTM + 5 m error	-9.54	12.03	9.61
DTM + 25 m error	-29.52	32.07	29.54
DTM + 50 m error	-54.54	56.96	54.56

Table 2: Statistics of height differences between intersection results and heights interpolated from DTMs (in m)

The 3D coordinate measurement procedure using orthorectified stereo images can be used in different applications and in particular for DTM correction, measurement of non-terrain objects (like buildings), and easy establishment of many control points to check the orthoimage accuracy (more details are given in [3]).

4. Building modelling by using orthoimages and Digital Surface Models (DSMs)

A research group at ETH has developed operational procedures for the automatic detection and vectorisation of buildings from digitised layers of the 1:25 000 topographic map with high success rate [7]. In some applications the coarse height of the building is needed, information which is however not included in the maps. This information can be acquired by the following procedure. The vectorised buildings are overlayed with an orthoimage (see Figure 4), heights within the building roof are determined, and an average or maximum height of the building is estimated by robust procedures that exclude gross errors and spikes due to small objects like chimneys. The height determination can be performed by matching corresponding features on the building roofs in orthorectified stereo images as explained in Section 3 (see Figure 6). This procedure can be automated because the known position of the buildings restricts the search space of the matching, and only a coarse building height, i.e. no precise 3D description of the roof, is needed. If no DTM exists, and thus no orthoimages can be generated, then image matching procedures can be used with the original unrectified images to derive a digital model of the visible surface (see Figure 5). Through overlaying of the building outlines and the DSM and robust filtering, again a coarse building height can be estimated. This procedure can lead to rapid establishment of 3D building databases, an important practical application.

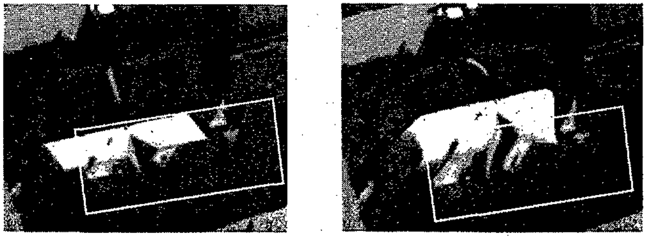
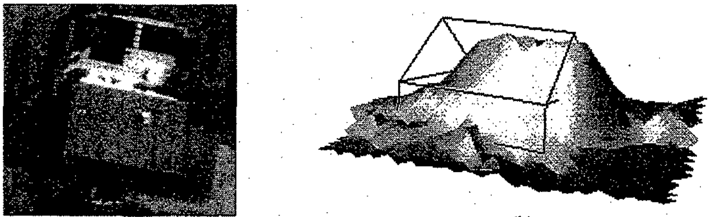


Figure 4 Coarse building modelling. Building outline digitised from a 1: 25000 map overlaid on an orthoimage from a DTM (left) and a DSM (right). Using a DTM buildings are unmodelled and lie on the ground, while using a DSM buildings are distorted due to DSM errors



(a) (b)

Figure 5 DSM generated using automatic image matching. (a) image of a building; (b) DSM with 0.25 m grid spacing and manually measured building outline

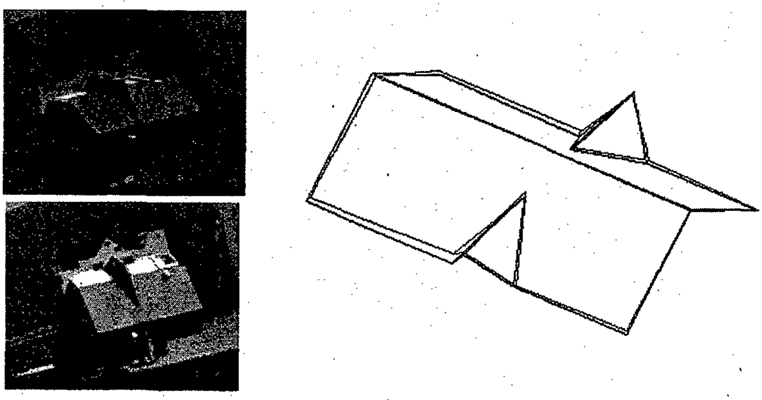


Figure 6. Left: orthorectified stereo images. Right: roof measured from stereo orthoimages (by image matching) and unrectified stereo images (manual measurements).

A second application refers to a project at ETH on semi-automated building extraction from aerial images. In this case the extracted buildings must be accurate and the roof model is more complicated than a simple horizontal plane. The strategy is shown in Figure 7. Orthoimages and DSMs are used to provide an indication as to where the buildings are. and an approximation of their shape and size. This information is passed to feature extraction and matching algorithms which derive 3D features. group them and select the best candidates that fit to the building model. The detection of buildings using orthoimages is based on the following principle. Stereo orthoimages should ideally be identical. Since the buildings are not included in the DTM which is used for the orthoimage generation. the buildings are wrong in the orthoimages. i.e. they are flipped over. A subtraction of the stereo orthoimages will indicate regions (of large differences) where buildings are. but also other regions like forests etc.. so building detection by this approach can not be automated. In automatically generated DSMs on the other hand buildings will generally appear as positive bumps. whereby matching errors can not be excluded. By combining the information from the stereo orthoimages and the DSM. the texture. amount and length of straight lines at the image position of the detected 3D bumps. and some assumptions on the building shape and size. buildings can be extracted and separated from other bumps like trees etc. (more details are given in [4]). Additionally. subtraction of stereo orthoimages that are generated by a DSM can be used for quality control of the DSM and manual or automatic corrections (Figure 8). In regions of large differences either DSM errors or radiometric differences will exist.

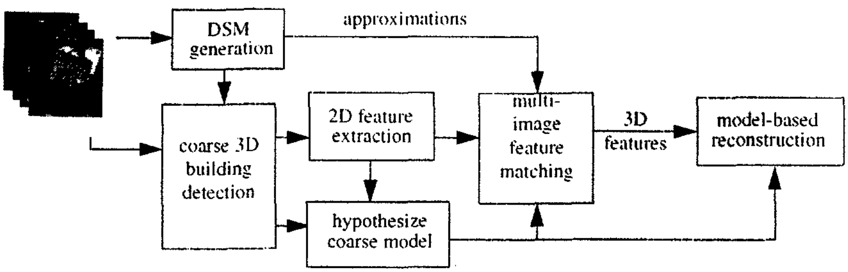


Figure 7 Strategy employed in semi-automatic building extraction from aerial imagery

Figure 8 Subtraction of stereo orthoimages that are generated by the use of a DSM. Regions of large differences (dark or light regions) indicate DSM errors. Errors occur especially close to surface discontinuities. e.g. buildings.

5. Feature extraction and change detection using image analysis techniques

Research efforts in automated feature extraction 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 man-made structures

The vast amount of the techniques and their results can not be presented here. However, it can be generally stated that the results of fully automated techniques are not precise and complete enough, include many errors and require extensive manual editing. Such approaches have been generally used with unrectified images, but can clearly be also applied to orthoimages. Feature extraction in orthoimages is simpler and easier than in regular images because in the former case certain attributes of objects to be extracted like length and width of a road, area of a lake etc. have known or bounded values which can be directly compared to the attribute values of the features that are extracted in the orthoimage. Furthermore, the existence of a priori knowledge in GIS can be favourably exploited in the direction of knowledge- and model-based object recognition. DTMs for example can provide slope information which can be used to decide whether two parallel edges extracted in the image are a road of a certain class with known maximum slope limits.

In change detection applications, multi-temporal orthoimages can be favourably used to highlight regions of possible changes and guide a manual or semi-automated feature extraction scheme. This is usually done by radiometric equalisation of the images, subtraction (or even better edge detection and then subtraction), elimination of small differences or binary thresholding of the difference image, and elimination of small isolated spots [8]. Attention should be paid to the fact that if the orthoimages do not have equal geometric accuracy, similar spectral characteristics, and image acquisition conditions (acquisition date, sun angle, and for satellite images atmospheric conditions), then the grey level differences will in many cases not represent regions of changes. In updating tasks, the deletion, addition or modification of objects of different classes has to be checked. Instead of blindly searching the whole image using a coarse generic model for each object class, the existing information in a database can be used to constrain the search space for deletion or modification of existing objects. New objects are very often related to existing ones (e.g. new roads start from existing ones) and thus the search space can again be reduced. The spatial and attribute knowledge of the "old" database information can also support the change detection operations by matching the database objects with the image objects [11]. The coarse generic object model can be substituted by specific geometric and semantic information for each individual object which can be retrieved from the database. Thus, verification of old and extraction of new features becomes easier, faster, with higher success rate, and can be automated to a higher degree. Since in many cases the geometric information stored in the database does not include height, the transfer of this information to the image can only be done if the image is orthorectified. Some ideas and preliminary results on revision of GIS databases using orthoimages and image analysis techniques are presented in [8, 9], while the first author also reports on new techniques introduced at the Survey of Israel for change detection and map revision. [1] use image analysis techniques and monoplotting for the semi-automated 3D digitisation of roads and other linear features, while [5] aim at an automatic updating of roads using knowledge from existing databases.

6. Conclusions

The use of digital orthoimages for monoscopic revision of 1:50 000 map data set has demonstrated the potential and merits of this approach. From the technical point of view this approach facilitates the change detection and ensures uniform and improved accuracy throughout the map data set. From the operational point of view this approach reduces significantly the time to perform revision compared to analogue methods, allows time-stamping of the revised data and facilitates the quality control process. From the systems point of view the combination of the Helava digital photogrammetric workstations for the production of the digital orthoimages with the CARIS GIS offering real vector-raster integration for the revision of the existing 1:50 000 digital databases proved to be quite successful.

Using orthorectified stereo images full 3D information can be extracted. Stereo orthoimages can be used in combination with planimetric map features to derive a coarse 3D model of buildings, or with DSMs and other image and object model related information to detect approximate position, shape and size of buildings, information which can be used in a subsequent processing for detailed building modelling. Semi-automated image analysis techniques have been used for the extraction of features, especially linear ones, while a combination with a DTM in a monoplotting mode can lead to 3D acquisition of non-DTM objects. In change detection applications multitemporal orthoimages can indicate regions of possible changes and in combination with information from a GIS database can support an easier, faster and more automated verification of old and extraction of new features.

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