DIGITAL CHANGE DETECTION FOR MAP DATABASE UPDATE

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ABSTRACT:

In almost all areas of our society there is an increasing need for well maintained and frequently revised digital map databases. Maintenance and revision of geo-spatial databases can be divided into 3 steps: Change detection, classification of changes and registration and updating of the database. Traditionally, three different methods have been used for change detection: field inspections; manual comparison of the map database and up-to-date orthophotos; superimposition of the map database on a stereomodel. All of them are labour intensive and costly. This paper focuses on automated change detection for a “building” layer in a fully 3D geo-spatial map database. The aim is the development of efficient change detection procedures for database maintenance in a production environment. An automatic change detection method, based on unsupervised classification used as input to an supervised (Mahalanobis) classificaion is presented. The method is evaluated on building registrations from the Danish TOP10DK map database, in combination with RGB (colour) and CIR (Colour Infra Red) aerial photos. The test case presented in the paper is from a residential suburban area.

1. INTRODUCTION

At the National Survey and Cadastre—Denmark (Kort & Matrikelstyrelsen, KMS) the map production is based on the digital topographic database TOP10DK. TOP10DK is a highly accurate, fully 3D, high performance topographic map database, where geo-spatial input data must meet high accuracy requirements and topological specifications (Kort & Matrikelstyrelsen, 2001).

The development and update of TOP10DK is therefore based on photogrammetry using aerial photos: Each spring, one fifth of the Danish area is photographed, resulting in 1200 photos, which corresponds to about 400 GB of image data. These photographs are used for the subsequent work with the updating of TOP10DK.

Previously, map updates have been carried out by actual remapping of the areas for each revision cycle, but in an entirely digital production cycle, it can be expected, that much work can be saved by detecting changes from the previous version of the map database and concentrating on the areas of change.

Change detection for mapping is, however, not a simple task: Although the intention is always to carry out the photo flights at approximately the same time of year, the natural, interannual variations of the vegetation coverage is of a magnitude that hides the primarily human generated changes sought for.

Furthermore it is almost impossible to take the photos at the same geographical position and with the same pitch, yaw and roll parameters as within the previous photo cam-paign, even when using GPS/INS systems. This means that the change detection must be carried out by comparing a new image directly with the map database (i.e. a raster-to-vector comparison), rather than by a simpler image-to-image (i.e. raster-to-raster) comparison.

Figure 1. Buildings are typically highly diverse and spec-trallyill-defined, when considered as a single group. The 4 examples shown above are found within an area of less than 1 km ^{2}

In this paper we present a procedure for change detection concentrating on buildings, which are particularly important mapping objects. The next step in the update process: the actual 3D object registration, is not considered here.

Since buildings (as it can be seen from figure 1) are most often characterized as being highly diverse and spectrally ill defined, they are hard to describe spectrally and therefore not easy to detect using image information only.

The aim of the automatic change detection procedure is to detect at least the same percentage of changes as a manual operator. On the other hand, it is acceptable if the change detection procedure causes a few false alarms, which can be rejected during the 3D object registration.

Currently, similar projects considering automatic change detection or semi-automatic map updates, are going on in Switzerland (ATOMI project), Holland (Top10Vector) and Germany (ATKIS).

In the Swiss ATOMI project, aerial color photos, a high resolution Digital Elevation Model (DEM) and a photogram-metrically generated Digital Surface Model (DSM) is used aiming at detecting changes and enhancing planimetric ac-curacy for the 2D VECTOR25 database (Eidenbenz et al., 2000, Nieder¨ ost, 2000, Nieder¨ ost, 2001). The surface model is used as primary data source, and image information is used primarily to discern man made objects from natural objects.

In the Dutch project, fully digital and multi spectral and multi stereo data from the *High Resolution Stereo Camera–Airborne, HRSC-A* (Neukum, 1999) is used for the update of the Top10Vector data base (van Asperen, 1996, Hoff-mann et al., 2000). The HRSC-A data set includes high-resolution(15 cm) spectral data (RGB and CIR) and an automatically generated high resolution surface model.

In the German ATKIS update project the focus is on registration of generic surface types (settlement, greenland, street, water etc.) (Petzold and Walter, 1999, Walter, 2000b). The ATKIS map database, is comparable with TOP10DK but the accuracy requirements are different as for TOP10DK (Kort & Matrikelstyrelsen, 2001, Arbeitsgemeinschaft der Vermessungsvervaltungen der L¨ ander der Bundesrepublik Deutschland, 1988).

The method for change detection uses a supervised maximum likelihood classification, with training areas created from the existing ATKIS map data base (Walter and Fritsch, 1998, Walter, 2000a). Using height information and multispecral images (RGB, CIR) in combination with the reduction to generic surface types, has shown that changes can be detected automatically with excellent precision (Petzold and Walter, 1999, Petzold, 2000).

2. DATA

The change detection procedure presented in section 3 below, is evaluated using datasets assosicated with the development of the Danish TOP10DK topographical map data base.

2.1 RGB Images

For the establishment and update of TOP10DK traditional RGB aerial photographs have been used.

All images are taken from an altitude of approximately 3800 meters leading to a scale of 1:25.000. Each image covers an area of 6km by 6km and has a forward lap of 60 percent and a side lap of 20 percent.

Since these images are all analog, digital versions of the images covering selected test areas have been generated. The images are scanned at a resolution of 21 µm, leading to a file size of 350 MB, and a pixel ground resolution of 0.5 meter.

2.2 CIR Images

In the light of experiments from the German ATKIS project (Petzold, 2000), additional Color Infra Red (CIR) images covering the same test areas have been taken. These images have gone through the same production workflow as the RGB images, leading to the same type of end product.

Using GPS/INS systems, the CIR images have been at-tempted taken at the same geographical position as theRGB images. However, as described in section 1, this does not mean that the two datasets can be combined directly on a pixel by pixel basis.

2.3 Digital Map Database

As target for the update procedure the building theme from TOP10DK has been selected. TOP10DK is, as earlier de-scribed, a fully 3D map database. It includes 51 object types (such as building, lake, highway etc.) organized in 8 classes (such as traffic, water etc.).

The precision of the database is better than 1 meter both horizontally and vertically.

For change detection in the building layer, only new buildings larger than 25 m^2 and changes of building size larger than 10 m^2 is considered.

3. METHOD

The change detection procedure presented is basically a classification based method, using the existing object registrations in the map database as training areas in order to determine the characteristics of the different classes (in this case buildings).

There are two major assumptions behind the change detection procedure:

- it is assumed that the number of changes in a given class (eg. building) is much smaller than the number of objects used to describe the class, which is valid for most urban areas.
- it is assumed that new objects share the same spectral characteristics as the existing objects.

Figure 2 shows the procedure schematically. The procedure can conceptually be divided into 3 high level processing steps, named *preparation, classification, and change detectio*n.

The preparation consists of two steps: *preprocessing* of data and *data fusio*n. These steps are carried out in order to prepare the data for the change detection eg. to unify the reference system for the different data types involved (raster and vector data).

The classification is subdivided into two steps: *clustering* and *classification*. Both steps are run a number of times as part of an *iteration* process in order to stabilize the classification.

The change detection is subdivided into two steps: computation of a *change map* by comparison of the existing map database to the classification result, and *post processing* of the change map, in order to reduce the number of false alarms.

Since every step in the process is self contained, it is simple to implement and experiment with different algorithms in a specific step without affecting the rest of the workflow.

In sections 3.1 to 3.7 the algorithms used in the different steps are described and in some cases alternative algorithms listed. The listings should not be understood as complete listings, but only as some additional examples.

3.1 Preprocessing

At the present stage of the development of the method, the preprocessing only consists of two operations:

- decorrelation of RGB images
- detection of shadows

The decorrelation is done by transformation of the three channels R,G, and B into R-G, G, and B-G channels. The detection of shadows is carried out by simple intensity thresholding.

Other possible operations include transformation into HIS color space or principal components, generation of NDVI (Normalised Difference Vegetation Index) images, calculation of statistical structual measures, extraction of edges, and evaluation of training areas.

3.2 Data Fusion

In order to use the objects in the digital map database as training areas for the determination of the class characteristics, image data (raster) and the map database (vector) is to be co-registered.

Generally this can be done in two different ways:

- by registration of the image data to the map database
- by registration of the map database to the image data

Registration of image data to the map database is the most used method. However the method has the disadvantage that image data has to be re-sampled as rectified images or orthophotos. In general, re-sampling causes an undesirable change in the spectral characteristics. Also, a high precision elevation model, including a description of buildings etc. must be available (Digital Surface Model).

Having a three-dimensional database like TOP10DK and the orientation parameters for the aerial images, it is possible to project the map database directly onto the image data using the basic photogrammetric equations (Kraus, 1993).

In this way a new image can be generated, which holds the objects (buildings) from the map database and corresponds precisly to the aerial image.

This method, which is used in this project, leads to a very precise co-registration, and eliminates the need for resampling of image data.

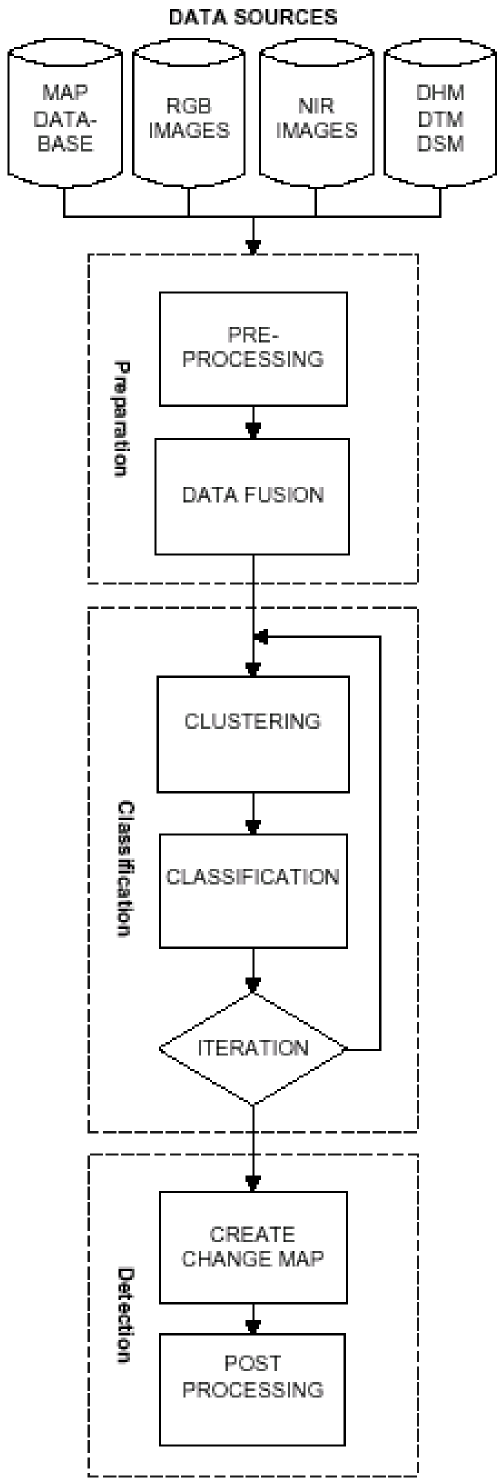

Figure 2. Change detection work flow—cf. section 3 for description

3.3 Initial Clustering

As indicated in section 1 some classes, e.g. buildings are spectrally ill defined and highly diverse. Such classes have to be subdivided into more unique subclasses.

This task is handled by splitting up all pixels registered as buildings (in the existing map database) in smaller and more uniquely descriped groups using a simple migrating means clustering process, based on the ISODATA algorithm (Ball and Hall, 1965).

The initial number of clusters is optional (arbitrarily set to 15) and the cluster centers selected at random positions in phase space. As the algorithm is iterative, the class centers are automatically moved around during the iterations, and the number of classes adjusted up and/or down (clusters splitted or merged) in the attempt of finding an optimal fit to the input data.

This leads to the definition of a number of subclasses, each being spectrally more uniform than the base building class. These subclasses are to be used (alone or in combination with descriptions of other classes) to classify every pixel in the image data.

Other clustering algorithms like neural network based or the recently published SYNERACT algorithm (Huang, 2002) could be used for this initial clustering process, and might improve the separation.

3.4 Classification

Using the class characteristics as input parameters a supervised Mahalanobis classification of the entire image is carried out. In this way all pixels are assigned to the class having the smallest Mahalanobis distance from the class cluster center to the pixel value (Richards and Jia, 1999). Threshold values (dependent on the class characteristics) are used to assign pixels being too far from the closest class center to a garbage class.

The classification can be performed using only one master class (eg. building) or it may include other classes (water, roads, forest, grass etc.) which might improve the classification result.

Other distance measures like the minimum distance could substitute the Mahalanobis distance measure, leading to a faster, but probably less accurate classification. Fuzzy logic and neural network based classification methods may also be considered.

3.5 Iteration

Since the result of the migrating means process depends on the positions of the initial cluster centers, the clustering and classification process are repeated a number of times (typically 5).

After this *Monte Carlo* process it is possible to accept only pixels identified as buildings in all (usally 5) steps, as actu-ally being buildings. This stabilizes the classification result considerably.

3.6 Computation of the Change Map

A change map can be computed by comparing a raster version of the buildings existing in the digital map database, with the set of results from the classification.

Pixels in this change map are split into three groups, de-fined as follows:

- **no change** pixels are *either* pixels registered as buildings and consistently detected as buildings *or* pixels not registered as buildings and consistently undetected as buildings.
- **potential change** pixels are *either* pixels registered as buildings and sometimes detected as buildings *or* pixels not registered as buildings and sometimes detected as buildings.
- **evident change** pixels are *either* pixels registered as buildings and consistently undetected as buildings *or* pixels not registered as buildings and consistently detected as buildings.

3.7 Post Processing

Since the change map includes all potential changes in the building layer it also includes some blunders and spurious pixels, due to misclassification, which must be removed.

This post processing can be done in many ways using different algorithms and the various steps may be done in different order.

The first step in the implementation is removal of the potential changes, leaving only evident changes. Afterwards spurious pixels are removed using plain mathematical morphology: closing (with a 3x3 circular kernel) is performed to fill out small gaps and followed by an opening (using the same kernel) in order to remove single pixels and small pixel groups.

The remaining change pixels are then clustered, and all pixel clusters smaller than the detection requirement (e.g. 25 m^2 = 90 pixels in the TOP10DK case) are removed from the dataset.

Finally shadow covered pixels are removed using an intensity threshold. These pixels are removed since object registration in these areas is difficult and in many cases impossible.

The result of the post processing is an image with a value of 1 for all pixels where a change has been registred and 0 everywhere else.

This is the final change detection product.

In order to improve the change detection, additional tests could be applied on a pixel or area basis: evaluation of size and shape of pixel groups, comparison of solar angle and nearby shadow, comparison with edges detected in the original image, check against other object types in the database etc.

4. CASE STUDY

The procedures are tested on the in section 2 described data and the latest update of the database took place 5 years before the photos were taken.

Test area: A test area situated in Kgs. Lyngby, a suburb 15 kilometers north of Copenhagen, Denmark is used for the evaluation. The area covered contains a traditional res-idential area (single family houses with gabled roofs, sizes and roof colors vary widely), highways, railroads and an industrial area.

Figures 3 and 4 shows an example of the entire processing chain from aerial photo to change detection map in CIR and RGB data, respectively.

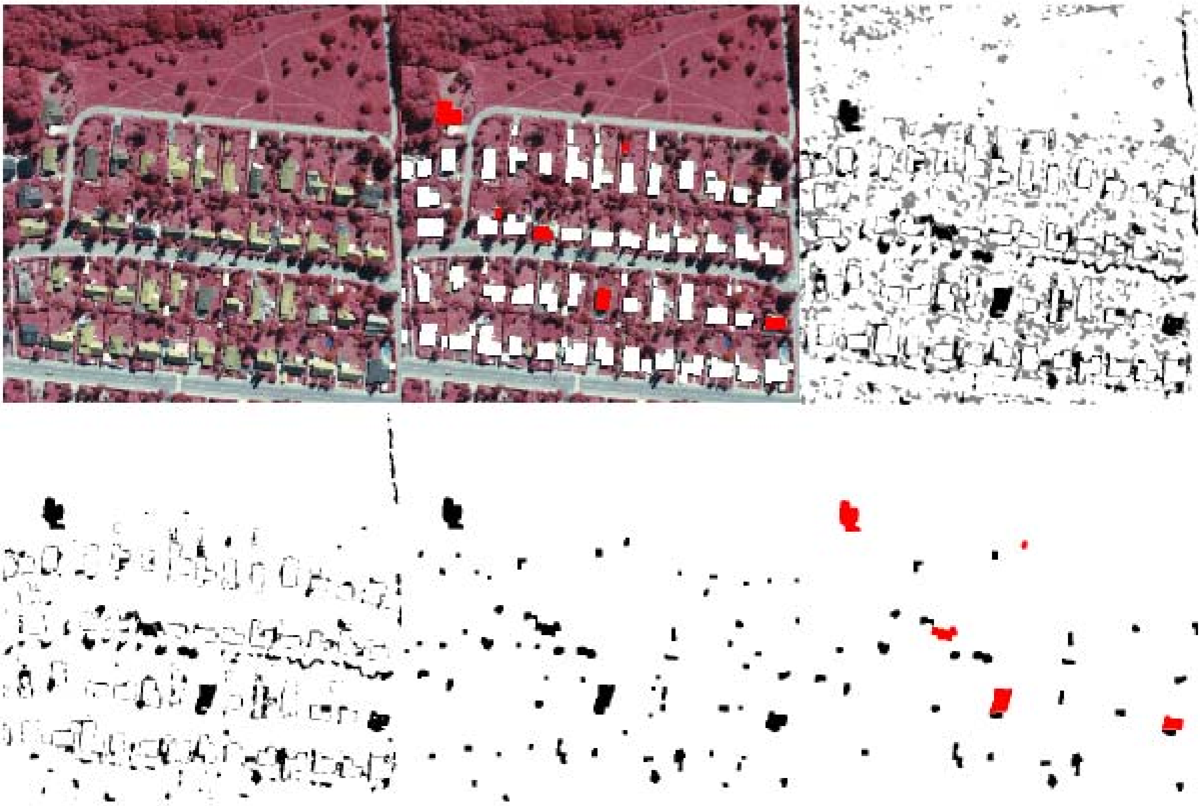

Figure 3. Steps of the change detection algorithm in CIR—cf. section 4 for description

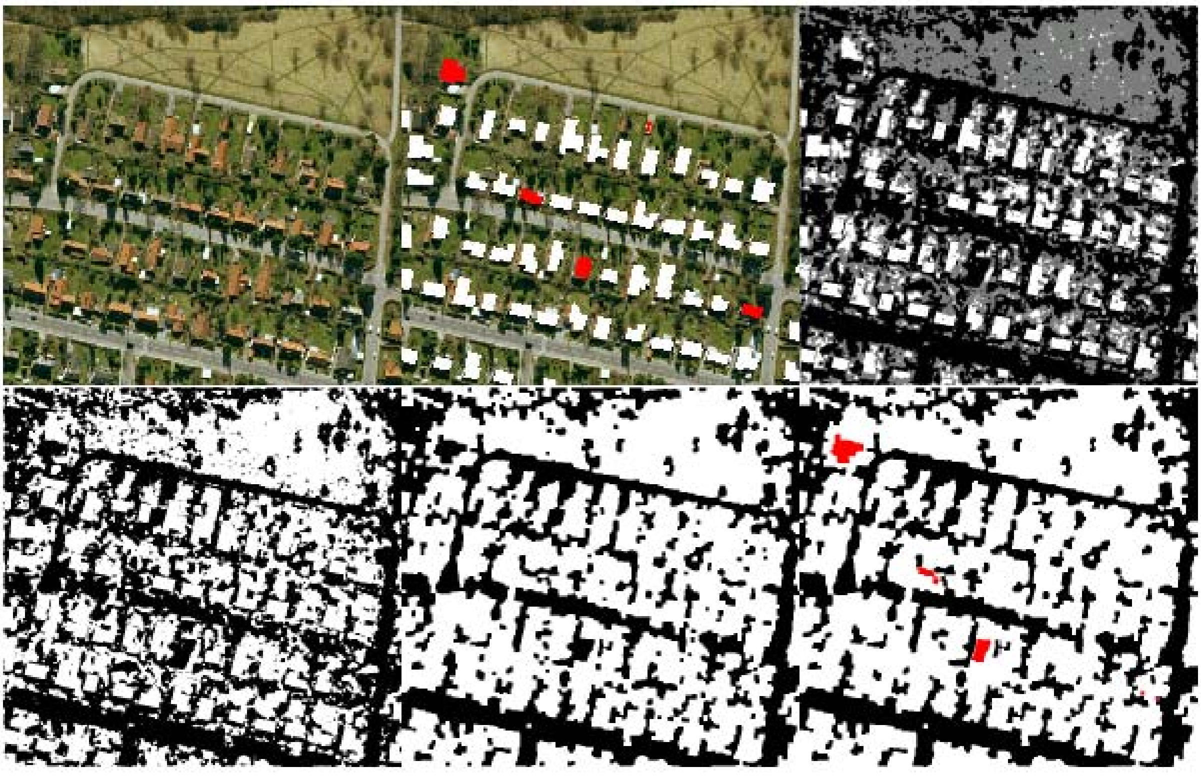

Figure 4. Steps of the change detection algorithm in RGB—cf. section 4 for description

The RGB image is 555 rows by 555 columns, and it includes 61 buildings, while the CIR image is 536 rows by 530 columns and includes 73 buildings.

5 buildings have been removed from the data set to simulate the effect of 5 new buildings since the last update of the map.

The two figures 3 and 4 have identical structures, which is as follows: The *upper left panel* shows the aerial photo. The *upper center panel* shows the result of the data fusionstep. The buildings masked in white are registered in the map data base while the five buildings masked in red are deliberately removed from the map data base to test the change detection algorithm. The *upper right panel* is the result of the comparison between the building mask and the initial classification result. White pixels mean no change, gray pixels mean potential change, and black pixels mean evident change. The *lower left panel* shows the evident change areas (no change and potential change pixels are removed). The *lower center panel* shows the effect of spurious pixel removal, and the filling in of gaps while the *lower right panel* shows the remaining areas of change after removal of all clusters smaller than the change detection limit (25 m^2), and shadow covered pixels.

Results:

The five change detection targets are all captured in the CIR case, while only three (and a tiny bit of the fourth) are captured in the RGB case.

As expected the CIR scene is by far the best to avoid misclassifications due to vegetation. In this test case the CIR scene is also the best to avoid misclassification of road pixels. The general experience is however that the discrimination between roads and buildings in the presence of asphalt roofs is virtually impossible, using RGB and/or CIR data alone.

5. DISCUSSION AND CONCLUSION

The method presented shows reasonable performance in the detection of new buildings in a CIR image, while it produces an unacceptable number of false alarms using a RGB image.

Experience from other areas has shown that in the presence of buildings with flat asphalt roofs, both CIR and RGB based change detection have big difficulties discerning buildings from roads.

Using CIR data shows reasonable results, but work has to be done in order to stabilize the classification process and reducing the number of false alarms. Especially the problem of discerning roads from asphalt roofs needs more attention.

The modular framework used enables the improvement of the process by the integration of new/additional algorithms into the workflow.

The performance of the classification may be improved by the introduction of other classes in the classification step and/or by an initial pre-clustering of the image data.

The post processing step is open ended, which leaves room for any number of additional checks and tests for reduction of false alarms. In this particular case, it would be obvious to use the large amount of additional data registered in the TOP10DK database.

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