Automated Change Detection for Validation and Update of Geodata

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Abstract

Traditionally, different manual, labour intensive and hence costly methods have been used for change detection. Conducting field inspections, comparing the map contents with the real world "on location" is one method. In another method two neighbouring images from a flight campaign are used and a stereo model generated. The digital map database is superimposed (in 3D) on the stereo model, and a stereo-operator locates the differences. Automating the update process for a topographic map database is, however, non-trivial, as it involves the comparison of the existing (vector based) map database to newer (raster based) remote sensing images in order to detect changes in objects. In this paper an automatic change detection method considering changes in the building theme and based on colour-infrared (CIR) aerial photographs in combination with height information (LIDAR, digital photogrammetry) is presented. Height information is used to determine the location of object which stands above terrain, and the CIR-Imagery is used to exclude vegetation, leading to a potential buildings mask. Comparing the existing objects in the map database with these extracted objects leads to a validation of the map database and hence change detection. The success of the method is strongly dependent on the representation of buildings in the DSM and hence the possibility to detect their locations. Therefore the method used for estimation of the digital terrain model from the LIDAR based digital surface model has show to be of great importance. Also the co-registration of the different data types shows to be a problem in practice. The artefacts resulting from this can be partially dealt with using mathematical morphology, but misregistration still accounts for a general degradation of the accuracy.

KEY WORDS: Photogrammetry, Remote Sensing, Change Detection, Classification, Automation, Infrared, DEM/DTM.

1 INTRODUCTION

At the National Survey and Cadastre—Denmark (Kort og Matrikelstyrelsen, KMS) the digital topographic database **TOP10DK** is the primary topographic product. The development and update of TOP10DK is based on aerial photogrammetry: one fifth of Denmark is photographed each spring before foliation, resulting in approx. 1200 photos (about 400 GB of image data).

Figure 1: Buildings are highly diverse and spectrally ill-defined, when considered as a single group. The last image (Lower Right) shows a building as it may be represented in a DSM.

Map updating can be carried out by a complete remapping of the area for each revision cycle, but much work can be saved by detecting changes from the previous version of the map database and concentrating on these areas of change. In this paper an automatic procedure for change detection concentrating on buildings is presented. The following step in the update process: the actual 3D object registration, is not considered here. This subject has recently been treated extensively by Niederöst (2003) and Süweg (2003).

As can be seen from figure 1 buildings are often highly diverse when it comes to size, form and spectral signature. They are therefore hard to describe by spectral information only. Adding height information to the process, e.g in the form of digital surface models, improves the distinguishing of buildings from other objects having a similar spectral response.

When introducing automatic change detection procedures, the aim is to detect at least the same percentage of factual changes as a manual operator is capable of. It is, on the other hand, acceptable if the change detection procedure introduces false alarms, as long as they are few, since they can easily be rejected during the actual 3D object registration.

1.1 Related work

Other European countries e.g. Germany, Switzerland, and the Netherlands have also established and completed digital map databases with national coverage in the past few years. The National Mapping agencies in these countries therefore face the same problem as the KMS and projects with similar aims considering automatic or semi-automatic map updating have been established.

In Germany the project for updating the ATKIS database focuses on registration of more generic surface types (settlement, grassland, street, water etc.) Petzold and Walter (1999); Walter and Fritsch (2000). The method for change detection uses supervised classification, with training areas automatically generated using the existing registrations in the ATKIS map data base Walter (2000). Experiments combining multi-spectral images (RGB, colour infra red – CIR) with height information and reduction of the information to generic surface types, have shown that it is possible to perform automatic change detection with a satisfactory accuracy Petzold (2000); Petzold and Walter (1999) (note, however, that the accuracy requirements for ATKIS are somewhat lower than for TOP10DK AVLBD (1988); Kort & Matrikelstyrelsen (2001)). The change detection leads to a "change map" where the generic objects are divided in three classes: no change, possible change and change.

In the Swiss ATOMI project, aerial colour photos, a high resolution Digital Elevation Model (DEM) and a Digital Surface Model (DSM) are used aiming at the enhancement of the planimetric accuracy for the 2D VECTOR25 database Eidenbenz et al. (2000); Niederöst (2003). The surface model is generated by auto-correlation in aerial photographs in the scale of 1:10.000 and is used as the primary data source. Image information (RGB/CIR) is primarily used to discern man made objects from natural objects (buildings vs. vegetation).

Data from the digital multi spectral camera *High Resolution Stereo Camera—Airborne, HRSC-A* Neukum (1999) is evaluated and used within the Dutch project Hoffmann et al. (2000); van Asperen (1996). The HRSC-A data set includes high-resolution (15 cm) spectral data (RGB and CIR) and an automatically generated high resolution surface model from stereo matching.

A new change detection project within the framework of EuroSDR has been started up this year. The emphasis is on development of methods for localising changes in land cover from very high resolution imagery; the integration of change maps in the updating process; and finally comparison of different methods for change detection EuroSDR (2004).

2 DATA

The change detection procedure presented in section 3 below, is evaluated using datasets which potentially could be used when updating the Danish TOP10DK topographical map data base.

2.1 CIR images

For the establishment and update of TOP10DK traditional RGB aerial photographs have been used. As CIR photos add valuable information for automatic change detection purposes, CIR photos have been taken and evaluated. Knudsen (2005) presents a method for converting CIR imagery to Pseudo Natural Colour imagery, making it possible to substitute RGB photos in the traditional production work flow. All CIR photos were taken from the same altitude as normally used when updating TOP10DK: approximately 3800 m leading to a scale of 1:25.000. Each image covers an area of 6 km by 6 km and has a forward lap of 60 percent and a side lap of 20 percent. The photos were scanned at a resolution of 21 μm, leading to 350 MB of data, and a spatial pixel resolution of 0.5 m at ground level. The photos were taken as part of a flight campaign in April 2000.

2.2 Digital Surface Model (DSM)

As described by Knudsen and Olsen (2003) it is very difficult to locate changes in the building layer using single aerial images and hence only using spectral information in combination with size and shape considerations. Therefore a high resolution digital surface model (DSM) with a grid size of 1 meter covering has been generated to facilitate the building detection. The dataset was collected and made available for these studies by the Danish engineering and mapping company COWI. Data were collected in May-June 2001 using the TOPOSYS1 system (Baltsavias, 1999; Toposys, 2004) which only record first responses of the pulse. The expected height accuracy is approximately 0.15 m.

2.3 Digital Map Database

The building theme from TOP10DK has been selected as target for the update procedure. TOP10DK is a fully 3D map database, including 51 object types (building, lake, highway . . .) organized in 8 classes (traffic, water . . .). The precision of the database is better than 1 meter both horizontally and vertically. For change detection in the building layer, only new buildings and/or changes of building size larger than 25 m^2 are considered.

3 METHOD

The method presented is thoroughly described in Olsen (2004b).

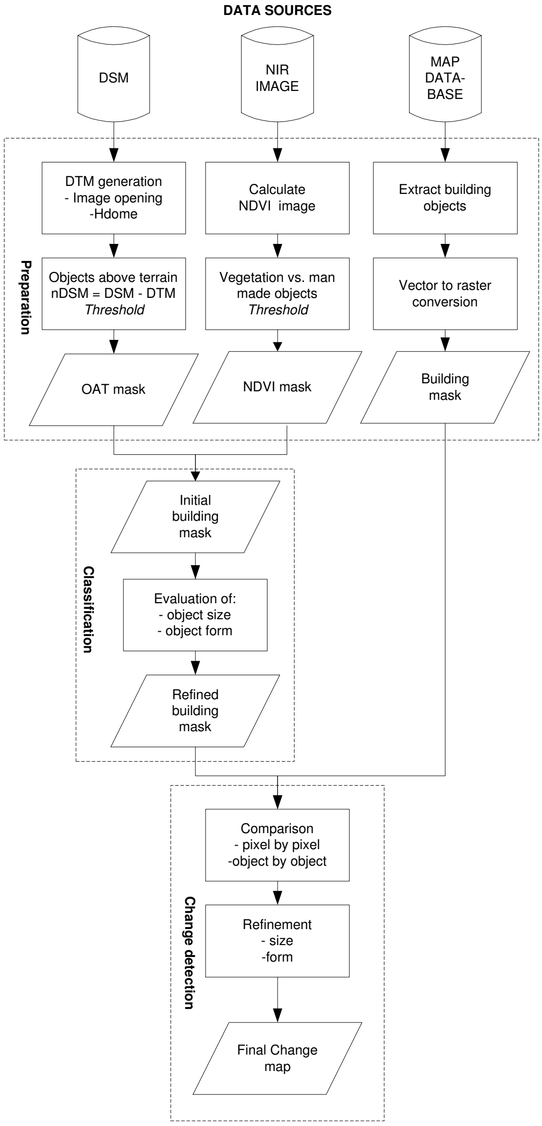

Figure 2: Change detection work flow—cf. section 3 for description

As it has shown to be very difficult to generate an unambiguous object model describing buildings using RGB imagery alone or in combination with DSM data (Olsen et al. (2002) and Knudsen and Olsen (2003)), the proposed method combines height information in the form of high resolution DSM data with CIR imagery.

DSM data is used mainly to distinguish between objects in terrain from objects above terrain. As buildings unfortunately are not the only objects which stand above terrain CIR imagery, in combination with shape and size parameters, is used to separate buildings from these objects (other man-made objects such as windmills, light poles etc. and single trees, small groups of trees, wooded areas).

3.1 The method step by step

The method which consists of three high level processing steps: *preparation*, *classification*, and *detection* is outlined in figure 2.

Preparation is composed of two steps: *preprocessing* of data and *data fusion*. In this step input data is brought into a common reference frame, and three masks are generated: a *normalized difference vegetation index (NDVI)* mask, an *object above terrain (OAT)* mask, and an existing buildings mask (which is extracted from the existing map database).

Classification is carried out in order to classify the object space into two classes; buildings and non buildings by creation of a *detected buildings mask*, which is finally *refined*.

Change detection is subdivided into two steps: computation of a *change map* by comparison of the refined detected buildings mask to the existing map database, and *post processing* of the change map, in order to reduce the number of false alarms.

3.1.1 Preparation:

As briefly described above the preparation consists of a *data fusion* step to bring the data sets into a common reference frame and a *preprocessing* step where various enhancement methods are applied to the data to prepare them for the change detection procedure.

Data fusion: When working with map databases and image data co-registration can generally be done either by registration of image data to the map database or by registration of the map database to the image data.

The most used method is registration of image data to the map database. However the method has the disadvantage that most image data types (aerial photos) have to be re-sampled as rectified images or orthophotos. For the data sets to fit completely to each other a high precision elevation model, including description of man made objects (buildings, bridges etc.) must be available (i.e. a Digital Surface Model, DSM).

Another way is to project the map database directly to the other data sets, e.g. onto the aerial images using the collinearity equations (e.g. Kraus, 1993). For this to work a database with (X,Y,Z) coordinates and the orientation parameters for the aerial images have to be available. This method, leads to the most precise co-registration, and eliminates any resampling of image data.

Co-registration is carried out using the first method.

Preprocessing: Various algorithms are applied to the data set to prepare them for the change detection process. The three most important processes are: (1) generation of a OAT mask (normalized Digital Surface

Model (nDSM)); (2) calculation of NDVI; and (3) Extraction of existing building mask.

Objects above terrain (OAT) can be extracted using a DSM. If the surface model is presented as a grey tone image with intensity representing the height, buildings will show as “blobs” with higher intensity than their surroundings and thus appear brighter.

A nDSM only includes objects which stands above terrain and it can be calculated as using a Digital Terrain Model (DTM): $nDSM = DSM - DTM$. If a DTM is not available it must be estimated from the DSM. A very simple method for DTM estimation using grey tone morphology is described by Weidner and Förstner (1995), and used in these tests. First a minimum filtering of the DSM is performed using a flat structuring element B (with a given size and form). In this way the minimum height in the area determined by the structuring element is assigned to the origin of the structuring element (pixel). This minimum filtering is followed by a maximum filtering, using the same flat structuring element. Performing the two steps in the described order equals an morphological opening: $\bar{z} = z \circ B$ and leads to an estimation or approximation of the topographic surface, the DTM. In order to eliminate all elements above terrain (buildings), the size of the structuring element must be chosen in such a way that it is not completely contained in a building. The size depends on the area to be processed. If a priori information concerning existing building sizes in the area is available the size can be fixed using this information. In the test presented in this paper the size of B is fixed to 25 m. The process is illustrated in figure 3.

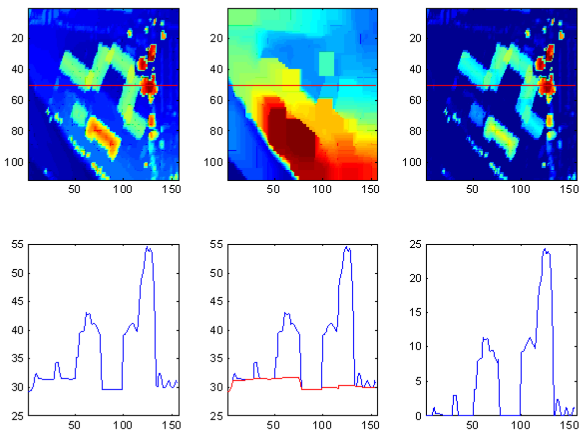

Figure 3: nDSM creation using artificial DTM. UL: DSM. UM: estimated DTM, $\bar{z} = z \circ B$. UR: nDSM = DSM - DTM. LL: DSM profile. LM: DTM profile. LR: nDSM profile. All profiles follow the red line in the DSM, DTM and nDSM respectively.

To distinguish man-made objects from vegetation, a NDVI approach has been taken in the implemented algorithm. NDVI is calculated as $\mathrm{NDVI} = \frac{\mathrm{ir}-\mathrm{red}}{\mathrm{ir}+\mathrm{red}}$; NDVI is well suited for distinguishing vegetated areas from man made objects. Values above zero indicate vegetation. To be certain that not too many man made objects are filtered out a threshold value above 0 can be used.

3.1.2 Classification:

Combining the NDVI mask and the OAT mask it is possible to split the objects which stand above terrain into two classes: vegetation and man made objects.

- vegetation: $(\mathrm{Height} \geq h_t) \wedge (\mathrm{NDVI} > \mathrm{NDVI}_t)$
- buildings: $(\mathrm{Height} \geq h_t) \wedge (\mathrm{NDVI} \leq \mathrm{NDVI}_t)$

From this an “initial detected building mask” can be created. This mask, is subject to further refinement by evaluation of the objects in the mask. Only objects that fulfils criteria characterising buildings (e.g. size and shape) are selected. First basic morphological methods (e.g. dilation and erosion) are used to patch small holes in the expected building objects. Then the objects are evaluated regarding size and shape. The criteria are established using the map specification manual which specifies the existing map database.

In the implemented algorithm the TOP10DK specification manual has been used and objects not fulfilling its minimum object size of 25 m^2 are eliminated.

The final result of this processing step is a detected buildings mask.

3.1.3 Change detection:

First a *change map* is computed by a pixel by pixel comparison of the existing map database (in a raster version) to the detected buildings mask. Since the change map includes all potential changes in the building layer it includes noise in the form of single pixels, and some false alarms due to bad co-registration. The single pixels are removed using morphological opening. The remaining change pixels are segmented, and pixel clusters smaller than the detection requirement (25 m^2 = 25 pixels in the TOP10DK case) and/or not fulfilling size and shape specifications for buildings are removed from the dataset, leading to a reduction of the false alarms and the final change map.

4 CASE STUDY

The procedure is tested on the data described in section 2. The latest update of the TOP10DK database was conducted five years before the photos were taken.

4.1 Test area

The test area used for evaluation is situated in Kgs. Lyngby, a suburb 15 km north of Copenhagen. The area contains many different types of buildings and houses since it includes a small industrial area; a church; a churchyard; a small train station; large strip buildings; and a gasoline station. The looks and shapes of the buildings as well as the heights differ a lot. Vegetated areas take up a large part of the area, and since the area also includes a highway, two bridges (one for pedestrians and one for cars) and a rail road, this causes a very special terrain structure. The area is also characterized by the fact that many changes have taken place since the establishment of the TOP10DK database.

Area: Approximately 700m $\times$ 500m. Lower left corner (E, N) $= (718450, 6187050)$. Upper right corner (E, N) $= (719150, 6187550)$. (E, N) coordinates are given in UTM zone 32. All images (RGB, TOP10DK and DSM) are 500 rows by 700 columns and approximately 70 buildings are included in the area. 72 registrations are included in the existing map data base. 13 new houses have been build since the last revision and 14 have been demolished.

4.2 Test data

All datasets are sub samples from larger datasets and they are brought into the same geographical reference by ortho rectification of the aerial photographs using an existing digital terrain model (DTM) with a grid spacing of 20 m.

4.3 Results

The results are visualised in figure 4. The first image shows the CIR image with the existing map database superimposed in yellow colour. The strong development that has taken place since the last revision of the map database is most pronounced in the right part of the image where 7 buildings have been demolished and 10 new buildings with blue roofing material have been built.

The second image shows the OAT mask; white pixels equals objects which stands above terrain.

The third image show the combination of the NDVI and the OAT masks. It can be seen most buildings in the area are described in a satisfactory way even though problems exist when buildings are poorly represented in the OAT mask or when vegetation covers the building. It can also be seen that large objects, which (consulting the CIR image) are not buildings are extracted as buildings as well.

The last image shows the CIR image with the changes found by the automatic change detection algorithm superimposed in green (new buildings) and red (demolished buildings). Yellow, purple and white ellipses emphasises detected changes of special interest which will be discussed in the following section. The results are summarised in table 1.

Approximately 100 percent of the factual changes in the test area have been detected by the algorithm.

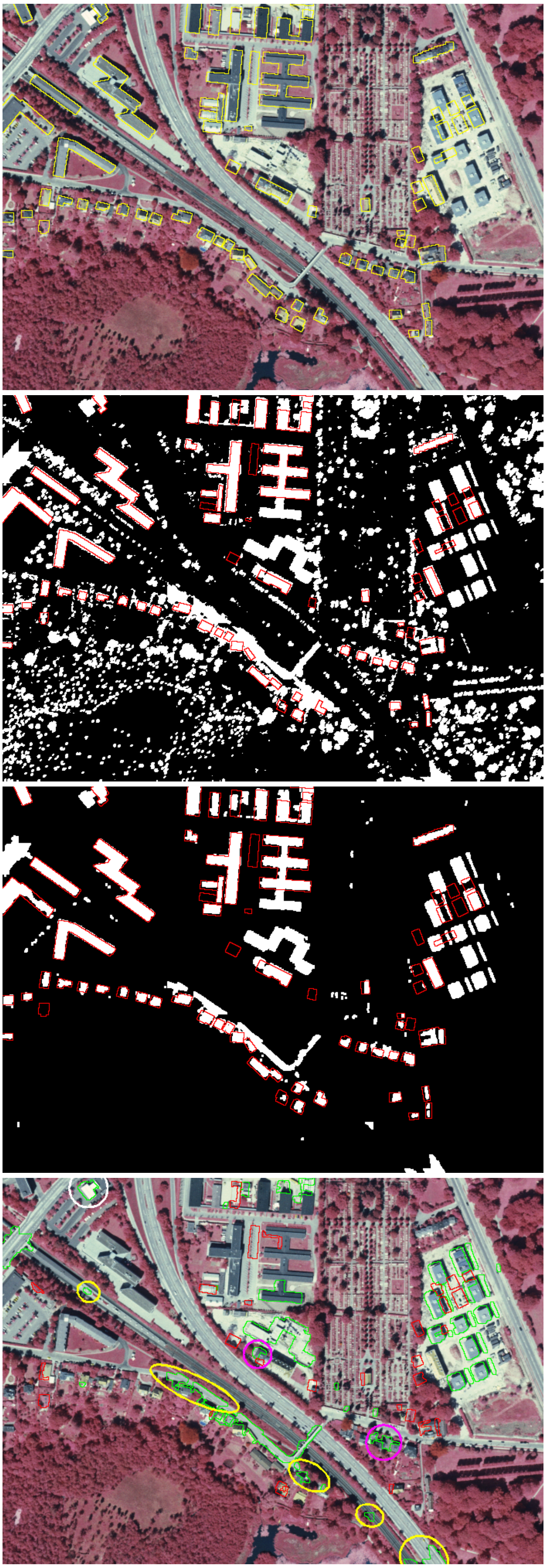

Figure 4: Results from the change detection algorithm.

	Factual	Detected
Demolished Buildings	14	29 (12)
New Buildings	13	46 (13)
Changes	27	75 (25)
False alarms	50	

Table 1: Statistical results

5 DISCUSSION

Of 13 factual new buildings in the area all 13 are detected by the algorithm. Additionally 33 objects are pointed out as new buildings (or additions) as well. Evaluating these objects, it can be seen that two of them are caused by bridges crossing the major road in the area or the rail road. These false alarms can only be eliminated using a more clever algorithm for nDSM generation. At least 7 (marked by the yellow ellipses) other false alarms are caused by the DTM generation algorithm or the thresholds used, leading to wrong estimations of the DTM and hence wrong estimations of objects standing above terrain. The problem occurs (amongst others) at a bicycle path next to the rail road. In this case the bicycle path is positioned on an "embankment" which apparently is more narrow than the size of the structuring element used. Using a smaller structuring element solves some of these problems. Introducing a smaller structuring element may on the other hand lead to buildings not being detected by the algorithm, as the structuring element may then be completely contained in the buildings.

Nine new objects next to the buildings with blue rooftops are detected. Consulting the nDSM the objects can be found as objects which stands above terrain, but the objects are not present in the aerial photo. This problem occurs as a result of the time difference between the two datasets (CIR and DSM). The DSM is approximately one year newer than the CIR image and therefore these objects may be factual changes which have to be checked in the next revision of the map database. The same argument can be used for two of the three new buildings detected in the upper middle part of the area.

Four objects are caused by the mis-alignment between the CIR and the DSM, as treetops are detected as standing above terrain but not removed by the NDVI mask, due to the leaning effect of the trees. Another factor playing a role is deep shadow. The NDVI in these areas will be low leading to areas which are covered by both vegetation and shadow potentially being pointed out as a building. Such objects are seen in the graveyard area and in the upper right part of the image at the highway.

Two changes (marked by purple circles) are due to a change in shape or size of the building. Evaluating the CIR image it can be seen that the building in the map database has been demolished, and two new buildings constructed; one of them partly at the same position as the existing registration.

One new building in the upper part left part of the area (marked by a white circle) is a factual difference but *not* a change, since it is a roof covering a gasoline station and, according to the map specification, roofs like this are not to be registered in the TOP10DK database. Such false alarms can only be verified by a human operator.

Fourteen buildings have been demolished in the area, and of those 12 are detected. The two buildings not detected are positioned at exactly the same positions as newly built buildings and hence not detected due to the direct comparison method used for change detection.

Additionally 15 objects are pointed out as demolished buildings (or building parts). Five of those are due to change in form or size of the of the existing buildings compared to the new data material. This can be due to the generalization of the buildings. Looking at the graveyard it can be seen that the generalisation used for the church, leads to a change being pointed out. Also a number of buildings at the same lot (in the the middle right part of the area) are represented by one object only, also leads to change being being wrongly detected.

Four changes are caused by mis-alignment between the various data types.

Three buildings, which are all visible in the CIR image, are pointed out as being demolished as they do not exist in the DSM and hence not in the OAT mask. It is most likely that the buildings *are* demolished, since the DSM data is newer than the CIR image, and therefore the registrations have to be validated at the next revision of the database.

6 CONCLUSION

Summarizing, it can be concluded that close to a 100% of the factual changes are found.

Two times the number of factual changes are pointed out as "false alarms". 50% of these false alarms are changes which have to be validated by a human operator as they are caused either by:
(1) objects which look like buildings but are not to be registered, or
(2) objects which are pointed out by the algorithm but can not be detected in the CIR image, as they did not exist at the time when the photos ware taken.

Most of the remaining false alarms are caused by the difference in geometry of the input data sources or by the algorithms (or thresholds) used for estimating the DTM.

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