IMPROVING GEO-INFORMATION RELIABILITY BY CENTRALIZED CHANGE DETECTION MANAGEMENT

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Commission VII

KEY WORDS: Change detection, web based repository, hypothesis driven image analysis

ABSTRACT:

A consortium called Mutatis Mutandis (MutMut), consisting of three Universities and eight producers and users of geo-information, was established in the Netherlands to streamline change detection on a national level. After preliminary investigations concerning market feasibility, three actions are being taken by MutMut: (1) construction of a centralised, web based repository for collection and exchange of changes detected by various actors, (2) design and implementation of an image based, automated change detection methodology, and (3) widening the scope of the project in a European context. This paper focusses on the second action. Objects in the database are used to formulate hypotheses, for which newer imagery may or may not provide evidence. In the latter case, older imagery is considered as well. If evidence for the hypothesis could still be found there, a possible change is detected. The paper shows preliminary results of a first implementation of this methodology.

1. INTRODUCTION

Change detection using remote sensing data is concerned with the identification of changes in land-use over time and has been widely studied since the early days of remote sensing. High-resolution satellite imagery (HRSI) will allow for change detection to be extended to application fields where more detailed information about ground features is required, such as urban planning, infrastructure planning or environmental protection and emergency intervention in urban areas.

After initial production, geographic information is subject to maintenance, in the form of revisions that are carried out at certain (regular) time intervals. For topographic mapping at a national level, revision cycles of four years have been common practice in most industrialised countries, also in Western Europe, whereas in the developing parts of the revision cycles may take more than a decade. As a result in all cases, geographic information tends to be outdated and, therefore, have limited reliability.

Under the research program Space for Geo-information of the Dutch government, we established a consortium where three Universities, as well as the major Dutch geo-information providers and a representative group of geo-information users are united under the name Mutatis Mutandis.

2. THE MUTATIS MUTANDIS PROJECT

Mutatis Mutandis (MutMut) focusses on cost reduction and efficiency increase in revision of geographic information by giving change detection a central position in national collaboration and in European research and development frameworks. Efficient geodata production is based on processing change. To protect quality and actuality of the database, changes have to be detected quickly and completely. Experience has shown that when change detection is not executed systematically, database quality soon deteriorates and investments evaporate. Mutatis Mutandis concerns the use of change detection and definition from airborne and spaceborne imagery to update geodata.

We recognized that different geo-information specifications, requirements and ambition levels amongst various organizations lead to a variety of independent change detection practices. For example, several actors detect the same changes, whereas other changes remain undetected for too long. A single change (mutation) usually affects objects in several databases, which concern, for example, different themes in the same region.

We are investigating a central change-detection repository, in the form of a web service, in which each provider records changes he detects providers and users extract changes that are relevant to them.

Here, the issue of relevance is user-dependent. It involves trivial criteria, such as geographic position (a municipality needs changes within its boundary), but also advanced ones, for example those that consider scale and semantics. This raises the question concerning and compatibility of detected changes, which we investigate by analyzing specifications of a broad range of providers and users of geo-information. The next question concerns the automation of selecting changes according to different criteria when querying the repository. A further step is to include an automated mechanism that verifies reported changes against high-resolution imagery.

The ultimate goal of the project is that comparison of existing geo-information with new high-resolution imagery will automatically suggest possible places for changes, which will greatly improve change detection efficiency, and prevent geo-information from getting out-of-date without notice.

Summarizing, Mutatis Mutandis pursues an improved, fast and cost effective change detection stategy, focusing on following activities.

- Single change multiple use; or development of a change detection web service at a national scale
- Research and development at a European scale towards automatic change detection on the basis of aerospace imagery

- Development of a communication and knowledge transfer platform to realize widespread utilization within a few years.

The first phase of the project investigated market feasibility and was finalized recently (Addink *et al.* 2006).

3. CHANGE DETECTION

The paper is focussed on the automatic detection of change in large-scale 3D Geo-information using multi temporal high resolution satellite imagery (HRSI) for the revision of geographic information. Generally, the revision frequency of geographic information is limited by two factors: data availability and labour.

Data Availability

Until recently, airborne image data (aerial photography) used to be the main data source for topographic revisions, but acquiring such data on a country-wide scale is very costly. Satellite imagery, on the other hand, is recorded much more frequently, but until the end of the nineties spatial resolutions were too limited for practical topographic application. Since the launch of IKONOS 2 in 1999, followed by Quickbird in 2001 and soon augmented by Orbview (2003) and possibly others in the near future, the data availability restriction is, at least technically, solved for a wide range of map maintenance applications, including topographic mapping, also at practical map scales, such as 1:10000 used as the standard in many countries.

With their high geometric resolution, the guaranteed repeat and revisit period of a specific area (temporal resolution) and its large footprint (about 15x15 km), high resolution satellite images are increasingly providing advantages over aerial images. As a matter of fact, the image pixel size of IKONOS images is corresponding to the information content of aerial images with a scale of 1:80,000; while QUICKBIRD images are even corresponding to aerial images of scale 1:50,000. Consequently research has focussed on using High Resolution Satellite Imagery (HRSI) in the production of Orthophotos, which are today routinely generated through HRSI. Orthophotos of scale 1:8,000 are generated today from IKONOS satellite images and those of scale 1:5,000 from Quickbird images.

Labour

The labour required for a complete revision cycle can be subdivided into change detection, updating and dissemination of information. When considering a certain period of time, in which several revision cycles take place, the change detection effort increases with the revision frequency, since for each cycle the entire new imagery must be compared with the existing information. The updating effort, however, only depends on the amount of change in the area during that period, and is independent of the revision frequency. In order to increase revision frequency significantly, therefore, automation of change detection is crucial. Finally, dissemination of geographic information, which used to require costly map design and reproduction, is not a technical problem any more in the age of Internet and GIS.

4. AUTOMATIC CHANGE DETECTION

Traditionally, change detection approaches have focused on pixel-based techniques. With the advent of HRSI sources and their reduced spectral resolution, pixel-based techniques are replaced by object-oriented change detection techniques, which focus on the analysis of groups of pixels being part of a single object. Developments in digital image analysis and computer vision have been leveraged, initially in the field of digital photogrammetry to improve the classification process, and are now extended to remote sensing applications working on HRSI. At present these three research areas are using a highly interdisciplinary approach to solve the complex problem of object recognition, in particular of man-made objects.

Change detection approaches based on statistical or decisional methodologies such as fuzzy or neural network models are also in use, but extensive learning capabilities are necessary for these models to resolve successfully the numerous ambiguities among objects inherent in most scenes. Semi-automatic procedures, integrating the human operator into the change detection process, are being used successfully. However the manual processing involved is very time consuming, and research is focussing on the automation of the entire process. Research and developments in digital image analysis and computer vision have proven key to this purpose, but even after a few decades of progress in digital photogrammetry and computer vision the challenge of automated image understanding and change detection is still far from being solved. Therefore, complete automation of change detection will allow for shortening of revision cycles from several years to the time interval in which new high resolution satellite imagery becomes available (say, once per month), without additional labour costs. This will greatly increase geographic information reliability.

Methodology

The research question is whether it is possible to obtain a significant increase in efficiency and effectiveness in the geographic information revision process by automating change detection.

To answer the question in the Mutatis Mutandis project, a method will be designed, developed, implemented and tested that performs automatic change detection. Under the expectation that it will be successful indeed, allowing for a positive answer to the research question, the algorithm implementing the method will be the most important outcome of the project.

The method will be based on a combination of two approaches, bottom-up (or data driven) and top-down (or hypothesis driven).

The first step in the bottom-up, data driven approach is combination of all available descriptive information about an image.

The primary data will be multi HRSI, in order to improve performance of the approach multi-source data will be fused. In particular 3-dimensional data, provided from stereoscopic acquisition of HRSI or from laser altimetry or from 3-dimensional vector data may be helpful for change detection, whenever available. (Vosselman *et al.* 2004; Vosselman *et al.* 2005). This step involves development of an algorithm to obtain an object-based description of the images.

Image segmentation based on edge detection will be applied to obtain a low-level features description of the data (segmented clusters). The process may be improved with additional segmentation based on texture, colour and shape analysis on both panchromatic and, multi-spectral image (eventually resampled).

All the available metric information on the extracted low-level features of each cluster have to be extracted in order to exploit the full information content of the HRS data.

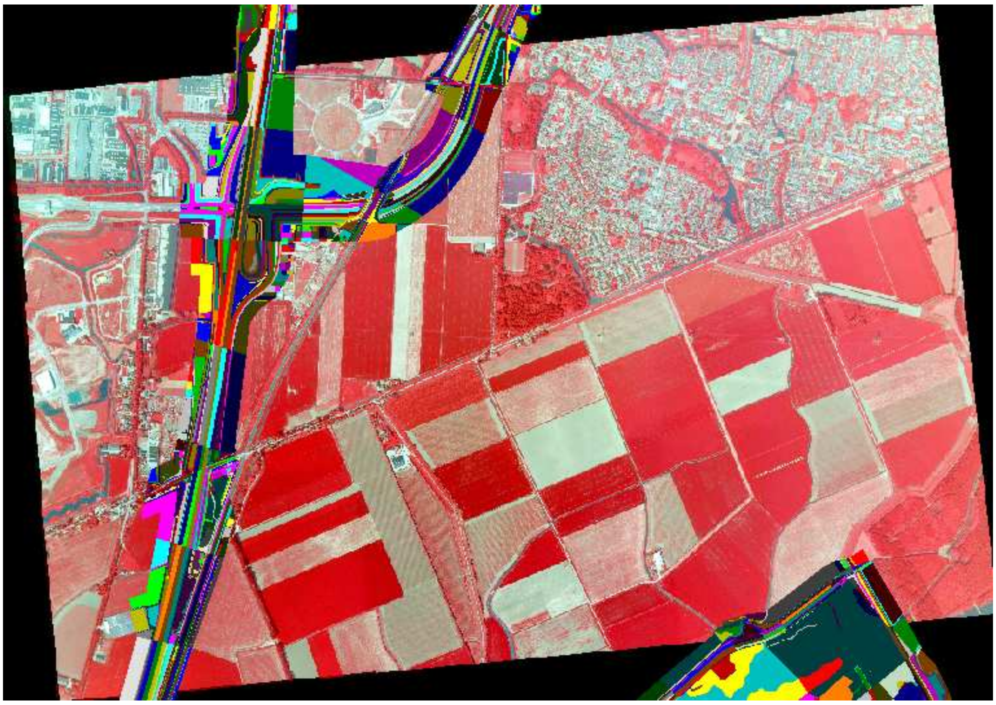

Figure 1. False colour composite of 2004 image with DTB2000 overlay

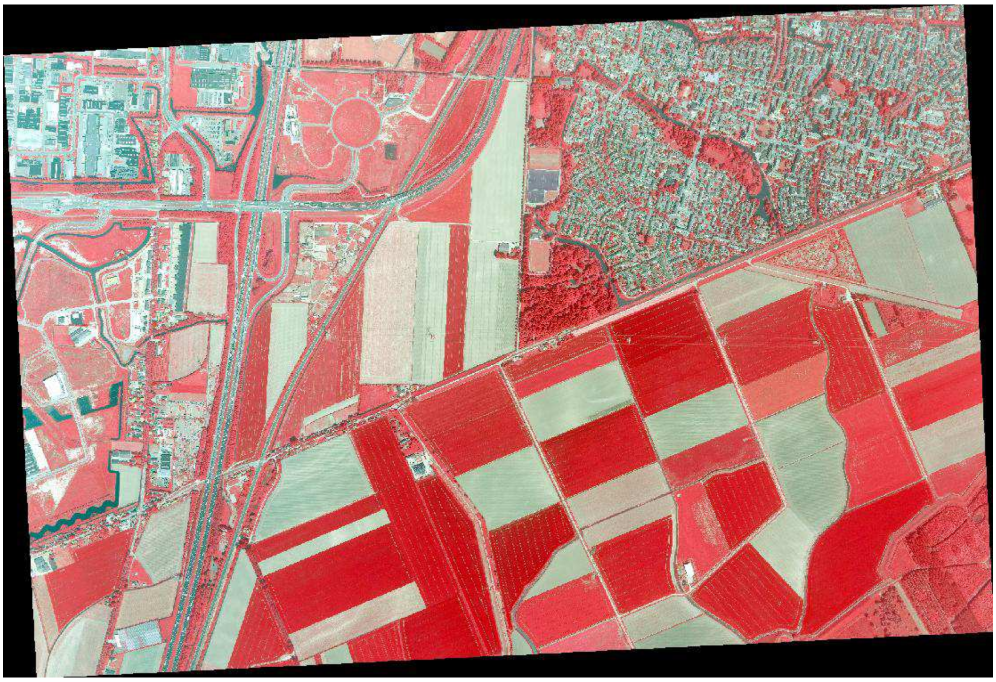

Figure 2. False colour composite of 2005 image

The second step is the fusion with 3-dimensional data to enhance the recognition process before obtaining automatic classification of the extracted features. At first the features will be further divided using different approaches based on height differences, on both radiometric and height gradient orientation, and on spectral/textural/color.

Moreover the creation of 3-dimensional data from imagery with or without additional laser data and the necessity of work with ortho-, or true-ortho-, or no-ortho images will be further investigated.

The top-down, hypothesis-driven approach involves the management of a geo-information database that contain all the temporal-geometrical information of the object. During a revision cycle the entire new imagery must be compared with the existing information: each object in the geo-information database forms a hypothesis, which is evaluated against new image data, including 3-dimensional data and other features derived using the data-driven approach. When a hypothesis is denied, a (likely) change is detected. In that case, as additional data source the image data from the previous revision cycle will be used. If the hypothesis would also be denied when evaluated against the previous image data, the database might contain meta-data explaining the discrepancy, and it can be further hypothesised whether this explanation is still valid in the new imagery.

Therefore, complete automation of change detection will allow for shortening of revision cycles from several years to the time interval in which new high resolution satellite imagery becomes available (say, once per month), without additional labour costs. This will greatly increase geographic information reliability. The project is expected to significantly increase the efficiency and effectiveness of the process of geographic information revision by automating change detection. 3-dimensional data will greatly help the process of object recognition. The object/hypothesis driven approach is an advance to the state-of-the-art within the project field and the adoption of image/meta-data fusion is even a novel concept.

5. CASE STUDY

We present a case study on change detection. In this case study we used two series of aerial photos, taken in spring 2004 and 2005, of the town of Dordrecht in the west of The Netherlands to detect spatial changes. The study yields examples of relevant and irrelevant changes. Relevant changes include the removal of a tree and the construction of a shed, irrelevant changes the removal of a car or the disappearance of people from the park. In future, one would like to automate the change detection procedure. The results of the case study show there still is much work to be done to achieve this automation. Hence, this paper should also be seen as an invitation to join the research efforts directed towards this automation.

Within the next phase of the MutMut-project we will work on an automated change-detection system to locate and identify changed objects in high-resolution images, either air- or space borne.

Once the web service is in the air, the databases are maintained much more efficiently than currently. However, the individual agencies are still responsible for the selection of the areas that are checked, which does not necessarily lead to a uniform coverage of the country. A central change detection system could ensure this uniform coverage and could lead to further cost reduction for the agencies. Change locations would then be detected centrally and identified as belonging to one of the general classes. Next, the individual agencies would then select the relevant locations and identify the changes in more detail. Change detection systems based on remote sensing data have the profound advantages that are inherent to remote sensing in general (Addink 2001; Coppin and M.E.Bauer 1996). Data are collected in a standardized manner, covering large and possibly remote areas, with a high return frequency. Data archives offer the possibility of looking back in time by using data that was not collected with a specific application in mind, which is a unique advantage of remote sensing data. A wide variety of change detection systems exist, all with their own specific limitations. Nevertheless they are in general limited for urban purposes because of 1) a limited spatial resolution of the images compared to the dimensions of change, and 2) the high spectral confusion of urban land cover types: the different function urban objects like buildings have is not necessarily reflected in spectral behaviour (Unsalan and Boyer 2005).

Although the spatial resolution of earth orbiting sensors significantly increased over the last years, e.g. with the launch of IKONOS and QuickBird having pixel sizes of 1 to 4 meters, the above two problems are still not fully solved. The enduser is interested in changes of objects that are smaller than can be detected by these sensor systems. Therefore, we use colour infrared photographs with a pixel size of 25 cm for the case study presented in the next section.

The camera used for obtaining the aerial data that was utilized for this case study is the Vexcel UltraCamD, a digital aerial camera that can produce large format images that previously only film-based cameras could. The camara features a setup of eight cameras. Four of these make the combination of the separate images into one large format panchromatic image, while at the same time a single coordinate system is retained and a single perspective center is enforced. The UltraCamD features imagery with a better than 12-bit per pixel dynamic range, compared to film cameras at less than 8-bits per pixel, and without any grain-noise. This gives better radiometry and matching quality than regular cameras. The remaining cameras produce multi-spectral imagery in four bands: Near-infrared, red, green and blue, having a coarser spatial resolution. Our case study made use of the multi-spectral imagery.

The top-down, hypothesis-driven change detection methodoloy presented above assumes the presence of three data sets: the geographic database to be updated, imagery of the same age as the database (probably used during the revision cycle that produced the database), and a newer image, against which the database will be compared in order to check it for changes.

As a database in this case study we used DTB2000, the digital topographic database maintained by the Dutch Ministry of Public Works containing all national highways, waterways and surroundings of 2000. The imagery used was the above-described Vexcel Ultracam imagary around Dordrecht of 2004 and 2005. Figure 1 shows an overlay of the DTB2000 polygons on the old (2004) image, and Figure 2 shows the new (2005) image. Unfortunately, therefore, the date of the first image did not correspond to the one of the data base, which makes the exercise slightly more difficult since the correspondence between the database and the first image is uncertain. Anyway, we are going to detect a change if a discrepancy exists between the database and the new image, which did not yet exist between the database and the old image. We can formulate this alternatively as: If there is a discrepancy between the database and the old image (assumed to have the same age), then apparently there was an image feature not suitable for mapping under the current specification or generalisation considerations. If the same discrepancy is revealed when comparing the database to the new image, it may be assumed to be still not worthwile mapping, and no change has to be detected. Only ”new” discrepancies cause detection of a change.

It should be noted that this is not a safe procedure in all cases. It does not account for moving cars, sun screens being down or up, etc. Cars might be accounted for by taking landcover information, pertaining to database objects, into account: newly appearing or disappearing objects with a rectangular shape may be less alarming when they occur on public roads or parking places. The distinction between sun screens and new attachments to existing houses from aerial imagery is an open problem, however.

When implementing this change detection strategy, a lot of options are open. First, we will assume here that the database (to be checked) contains a complete segmentation of the region under consideration: the database consists of area objects, represented as polygons, such that every location in the region belongs to exactly one object. The problem reduces now to checking for changes inside each object. Also the appearance of a new object (for example a newly built house) implies that an existing object (an empty parcel) is modified.

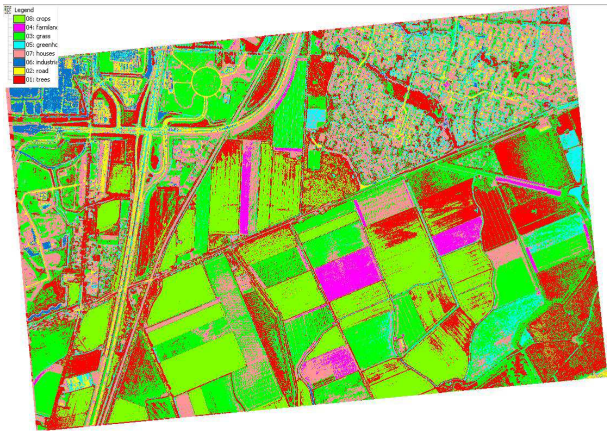

Figure 3. Maximum Likelihood Land Use Classification of 2004 image

A second option concerns to which extent attribute information in the database should be taken into account: the above-mentioned public roads and parking places where cars may change presence and position, for example, but also vegetation cover in parks and gardens, fall into this category.

An interesting question, to be further investigated as well, concerns what type of data or information will be derived from the imagery, in order to be compared to the database content: will this still be reflection values, or shall we prefer derived features, either spatial, such as lines, edges and texture, or spectral such as NDVI or PCA? Or perhaps the imagery should first be classified according to land cover, or even segmented by object-oriented classification software, such as eCognition?

Unfortunately, land cover (not to mention land use) classification is an increasingly difficult task as spatial image resolution ”improves”, because classes are getting more and more heterogeneous due to larger internal variability within objects. Multispectral classifications of imagery produced by airborne digital photogrammetric cameras, therefore, tends to give disappointing results (Figure 3). We expect that object based classification approaches, especially those that estimate class proportions within objects, are a more suitable approach (Gorte and Stein 1998).

Without answering these questions here, we present a very first attempt to implement the above-described change detection strategy. We would like to assume that a database object is represented in the old image as a homogeneous region, and that a more heterogeneous appearance in the new image signals a change. However, many database objects appear to quite heterogeneous in the old image already: These are accepted as “unchanged” compared to the new image if the heterogeneity remains constant.

This leads to the following algorithm: Consider all database objects, one by one, and compute for each object the standard deviation of all pixel values within the object in the most distinctive spectral band (this happens to be near-infrared). By doing this for both images, we obtain two standard deviations for each database object, one per image. In an unchanged object, these standard deviations should be similar. Note that this will be also the case when a crop change occurs in an agricultural field between one year and the next; only if a field is newly subivided (or subdivided differently) a change will occur. Therefore, a standard deviation change (*i.e.* absolute difference) that exceeds a threshold is assumed to signal a change. The polygons in which this happens (in a subset of the study area) are drawn as an overlay on Figures 4 and 5. The results are far from perfect yet, but further investigation seems worthwile.

6. CONCLUSIONS

In this paper, we presented a nation-wide appraoch to manage and commucate detection of changes in geographic databases, signalled by multiple data providers, over multiple data users, by using a web based chage detection repository. Moreover we showed a design for a image based, hypothesis driven change detection algorithm, taking multiple-date imagery, as well as the content of the existing information, into account. Although the algorithm in its current form is rather rudimentary and has a lot of room for improvement, the first results are encouraging.

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Figure 4. Preliminary result: Changed objects between 2004 and 2005, shown on 2004 image

Figure 5. Preliminary result: Changed objects between 2004 and 2005, shown on 2005 image