THE *MUTATIS MUTANDIS* PROJECT: SINGLE DETECTION, MULTIPLE USERS – CHANGE DETECTION USING HIGH SPATIAL-RESOLUTION IMAGERY IN DUTCH URBAN AREAS

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ABSTRACT

Ministries, municipalities, survey departments, and commercial mapping companies are all interested in changes that take place in our living environment. These changes comprise new houses or constructions, new roads, logged trees, a two-lane road changed into a three-lane road, et cetera. Each agency performs its own survey changes through a web service. Besides, the research groups in the project, represented by the authors, investigate possibilities of change detection using high-resolution earth observation imagery.

The project started with an inventory of the present survey methods, what potential users expect from the sharing of detected changes and the costs and benefits of the sharing. The main conclusions are that, despite the application of widely differing survey methods, all data providers and users may benefit from sharing changes via the web service. They expect the sharing will lead to more complete, actual and correct geographical data. In addition, it will probably lead to considerable economies and increase of revenues because of the selling of higher quality data.

The research groups in the consortium will focus on the development of an automated change detection system using Very High Resolution Imagery. This system will eventually feed the web-service database, thus reducing the input required from the data providers. The change detection system will be object-based and will combine spectral, shape and neighbour information of objects with knowledge from the previous situation to detect and identify changes. It will incorporate knowledge on 1) logical transitions of objects, e.g. a road intersection changes into a roundabout, a roof is extended with a roof vault, 2) variations of objects that do not change the object description, e.g. a tree that lost its leaves, the arrangement of cars in a parking lot, and 3) variations in the images that prohibit reliable observations, e.g. clouds, smoke.

The presentation will highlight the findings and developments within the different phases of MutMut. Besides, it can be considered an invitation for European partners to collaborate on the development of the change detection system within a European framework.

INTRODUCTION

This paper serves two goals. The first goal is to present the results of the first phase of a Dutch project on sharing changes in geo-information: *Mutatis Mutandis* (i). This first phase investigated the possibilities to set up a web service. Participants can upload their detected spatial changes to this future web service and can download the changes detected by other participants. We investigated the current practices of potential users of the web service and how they would benefit from the web service in terms of quality and economies.

The second goal is to discuss the limitations and possibilities of change detection using remote sensing. 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.

MUTATIS MUTANDIS

The *Mutatis Mutandis* (MutMut) project is sponsored by the Dutch government as part of the 'Space for Geo-Information' program (ii). The project brought together fourteen participants who are active as researcher (such as the authors of this paper), consultant or provider of geo-information in The Netherlands. The geo-information providers in the project consortium are the national Topographical Survey/Land Register, Statistics Netherlands, the AVV Transport Research Centre (AVV) and the AGI Geo-information & ICT Centre (AGI) of the Ministry of Transport and Public Works, the Large-Scale Base Map of The Netherlands (GBKN) and Navteq car navigation. Currently, all providers and their end users carry out independent change detection surveys to update their geographical databases. This is highly inefficient, taken into account their common goal: data maintenance for the entire country. One of the solutions for this inefficiency is the sharing of detected changes via a web service. This will lead to a wider availability of detected changes, which may result in faster updates and taking account of more changes in updates. In addition, sharing detected changes means that users of the web service can work more efficiently and hence save costs. Moreover, better geo-information may generate extra revenues because of its enhanced added value for the web service's potential users: the providers of geo-information in the consortium and their end users, such as water boards, provinces and energy suppliers.

This paper presents the results of the examination of the above hypotheses about the web service. We interviewed six providers and eight end users about how they currently detect changes, how they would incorporate the web service in their change detection process and what they expect to gain from it. Next, we carried out a cost-benefit analysis to see if the web service will generate a profit for the total group of its potential users.

Current sources for change detection in geo-information

Currently, the potential users of the web service apply a wide variety of methods to detect changes in spatial information and update their data. From the interviews it became apparent that change detection is performed with non-automated methods and that the most important sources for change detection are:

1) Remote sensing images: although not automated, predominantly providers of geo-information use aerial photographs to detect spatial changes.

2) Fieldwork: internal or external personnel check the status of the objects in the field. This is a common method among the end users but far less common among the providers.

3) Clients/users of geo-information: this is the most important source of changes for the providers. The AVV even promises a free new database if users report errors in the database. The GBKN already has an early version of a change detection web service for its own clients.

4) Government and other organisations: some providers and end users get information about physical planning projects from the government, such as construction plans for new roads or

houses. Almost all end users use the geo-information from the providing organisations (e.g., topographical maps from the Topographical Survey) to update their databases.

5) Other sources: this group of sources varies from new versions of the Yellow Pages and the telephone directory to reports by emergency assistance such as fire brigades or ambulances. They report to the AVV when they were called to a street they could not find in their database.

With a web service for sharing spatial changes, end users could cooperate in the fieldwork. They may indicate areas where they are going to detect changes and others may join, which leads to economies of scale. In addition, although end users are already an important source of changes for their own provider, with a web service they could easily report errors to *all* providers. Almost all end users work with geo-information from the providers in the consortium. This means that sharing spatial changes with the providers is beneficial for themselves as well when the shared changes lead to better geo-information.

Qualitative benefits from a web service for change detection

Since providers and end users have different goals with their geo-information and gather it from different sources, we learned from the interviews that their expectations differ as well. We nevertheless noticed three main groups of expectations:

First, the potential users expect enhanced actuality and completeness of their databases. Most end users and providers think this is the most important benefit they could get from the web service. By sharing the changes obtained from multiple sources, they are disseminated *earlier* and to a *wider group of users*. Moreover, it also means that more changes can be incorporated in updates. The potential users expect this to lead to an improved quality of their geo-information.

Secondly, the geo-information not only becomes more complete, but also increases in correctness. Instead of an individual provider checking its own data with its own survey, with a web service it is possible to use external survey data to improve the checking. Especially some providers would welcome the web service as an independent validation tool.

Thirdly, the web service could aid in saving money by working more efficiently. The potential users anticipate that it helps to know where other organisations have detected spatial changes. Then they can focus their survey on that area or use the uploaded changes directly. Similarly, it also helps to know where no changes have occurred. That area can be skipped when surveying, which saves money. Most potential users nevertheless value the improved data quality more than the saving of costs.

Both geo-information end users and providers indicated that they would mostly use the web service as an extra information source on changes instead of replacing their original sources with it. Because they want to be sure of complete, correct and actual web service, almost all end users of geo-information favoured a validation of the shared changes using aerial photos or spatially high-resolution satellite images. Providers were nevertheless already satisfied with a non-validated web service. A validated web service receives a wider acceptance yet is more expensive. Hence, we examined the costs and benefits of both the validated and non-validated web service.

Economic benefits from a web service for change detection

The potential users' first aim is improved data quality; lower costs are merely a welcome side effect. Still, the web service itself will not survive if its costs are higher than the potential benefits for the group of potential users. Consequently, we conducted a cost-benefit analysis to see if the web service is not only desirable, but also economically feasible over a five-year term.

The costs for the web service are those for the technical site of the service and for the validation of the shared changes. The benefits can be split in direct and indirect benefits. Direct benefits are not revenues, but expenditure saving by increased efficiency and cooperation through the web service. Indirect benefits are the extra revenues because of the web service. These are for instance the increased sales of car navigation databases or the increased payment of real estate taxes. The latter example is however not a direct societal but only a governmental benefit. We have therefore split the indirect benefits in benefits for non-governmental and governmental users. Additionally, there are external benefits that we cannot quantify (yet). These are for instance better spatial planning decisions or truck drivers that easier reach their destination because of better road maps. We left these out of the analysis.

Table 1: The results of the cost-benefit analysis for the validated and non-validated web service for sharing of changes in geo-information. Amounts are in million euros over a five-year period.

	Non-validated web service	Validated web service
Web service costs (WC)	0.1	0.1
Validation costs (VC)	0.0	12.0
Direct benefits (DB)	3.2	26.0
Indirect benefits (IB)	2.5	17.4 (30.6 for government)
Net result ((DB+IB) – (WC+VC))	**5.6**	**31.3 (61.9 with government)**

Table 1 shows that both the non-validated and the validated web service result in a profit for the total group of potential users. Although the costs are less for the non-validated service than for the validated service, its benefits are also lower, which leads to a lower net result. This is because end users will probably not use a non-validated web service. Consequently, they will not experience its benefits either. For the validated web service, governmental benefits, such as less fraud with subsidies and higher tax revenues, make up a large share of the expected benefits. Even if we omit these governmental benefits and take account of the validation expenses of € 12 million, the net result of the validated service is almost six times higher than for the non-validated service (Table 1).

In short, both the results of the interviews and the cost-benefit analysis show that a validated web service is worthwhile and feasible. Such a web service would enhance the quality of geo-information. Partly because of this enhanced quality and partly because of economies, it would lead to considerable financial benefits for the Dutch users and providers of geo-information.

CONCEPTS FOR AN OBJECT-ORIENTED CHANGE DETECTION SYSTEM

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 (iii; iv). 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 (v).

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.

With object-oriented classification the effect of spectral confusion is reduced by the availability of other variables on shape and neighbourhood characteristics. Indeed, classification results improve significantly with the object-oriented approach (vi); in general for all land cover classes, but also for the urban classes (vii).

Changes in remote sensing imagery

When comparing images covering the same area at different dates, different categories of changes can be found:

1) Relevant changes include those changes that the agencies are interested in. They include for example newly build houses, roof vaults, and widened roads. The interviews with the agencies executed in the first phase of the project revealed that in general annually 5 to 10% of the objects changes. For those changes, exact location data and thematic information is required. The different agencies can then decide whether a detected change is relevant to them and can include the object in their data maintenance trajectory.

2) Irrelevant changes appear for example on parking lots where cars occupy different places, on highways with and without traffic jams, trees with more or fewer leaves, and in gardens with or without parasols. The thematic description of the objects will in those cases not change as it concerns a modification of a single object and not a conversion from one object into another. Spectrally the appearance of the objects might show considerable differences, however, so a sort of object profile, describing different states of an object, seems desirable to recognize different appearances of a single object.

3) Technical image aspects can produce differences that are not caused by changes or modifications of the objects as described in 1) and 2). Sources for these differences are for example viewing angle, sun angle, overall brightness, and geometric accuracy.

A change detection method should distinguish between these different categories of changes as accurate as possible, and eliminate changes from 2) and 3) as much as possible. This requires the combination of change detection techniques with knowledge-based techniques (to recognize changes from category 2) and partly 3) like shadows appearing in different directions) and technical operations (to eliminate the effects of 3)).

The proposed method

One of the possibilities we may develop is an object-based change detection method that starts off with objects from t=0 and compares their attributes with the values at t=1. Attributes will be mean spectral characteristics like in per-pixel methods, but also spectral variance, and sub-object characteristics like spectral attributes and size distribution. Technical information on the images will provide detailed information on the object-profiles used to eliminate changes from category 2). Sun angle determines for example the direction of shadows. When the viewing angle is identical, but the sun angle changed, an object profile might consider the east side of a building appearing darker and the south side lighter in one of the two images, leading to a possible false alarm. Next to attribute comparison, a pixel-based change detection method operation can be applied to the two images. The output preferably shows a change/no-change map, which can either be segmented to detect changed (sub-)objects, or which can be related to the objects defined at t=0.

First impressions of a case study

For the project we have two aerial false colour photographs of the city of Dordrecht. They are taken on 8 June 2004 and 27 May 2005 at 1:00 pm and 10:13 am, respectively. Both photos are orthorectified and have a pixel size of 0.25 m.

The three change categories are all present. The second category, showing irrelevant changes, outnumbers the other two by far.

Examples of relevant changes are new buildings (Figure 1) and roof vaults added to existing houses (Figure 2).

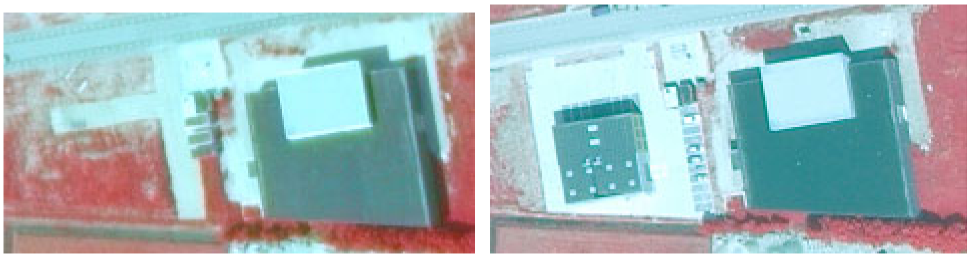

Figure 1: Industrial building that did not exist in 2004 (left) but which is present in 2005 (right)

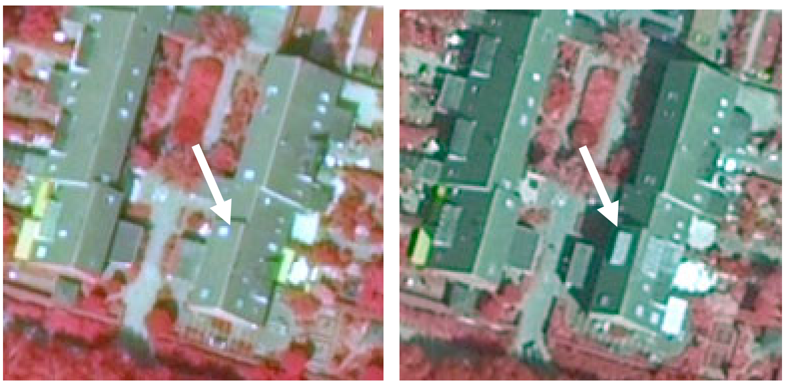

Figure 2: Roof vault added to existing house (left 2004, right 2005)

Although the photos are taken at almost the same moment of the year (12 days apart), the growing season shows large differences. While some trees are in full-leave in one photo, they are hard to recognize in the other (Figure 3). The same difference in phenological stage exists for agricultural fields. As expected, cars cause many irrelevant changes as well. Another example of irrelevant changes is shown in Figure 4 with sunscreens. This figure also shows a technical image difference: image brightness. In Figure 5 another technical difference is displayed. The recording time of the two images differs three hours, which results in a sun angle difference of 45° and consequently of shadows cast in directions 45° apart.

Figure 3: Phenological differences between the images. Note the differences between the trees right beside the buildings, which can hardly be recognized in the right picture, and the agricultural fields at the upper left and at the bottom of the pictures.

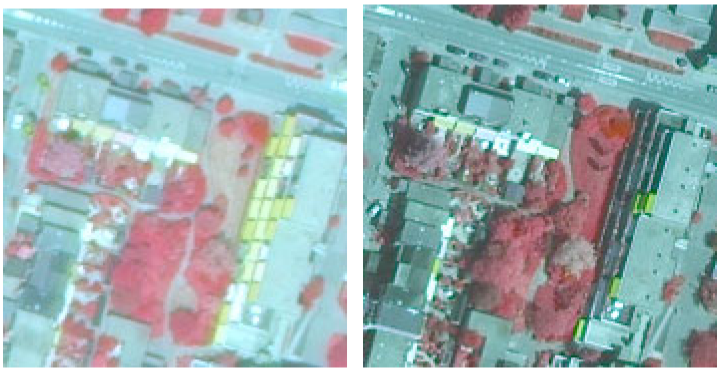

Figure 4: Apartments with sunscreens (displayed as false-colour Green). Also note the overall brightness difference

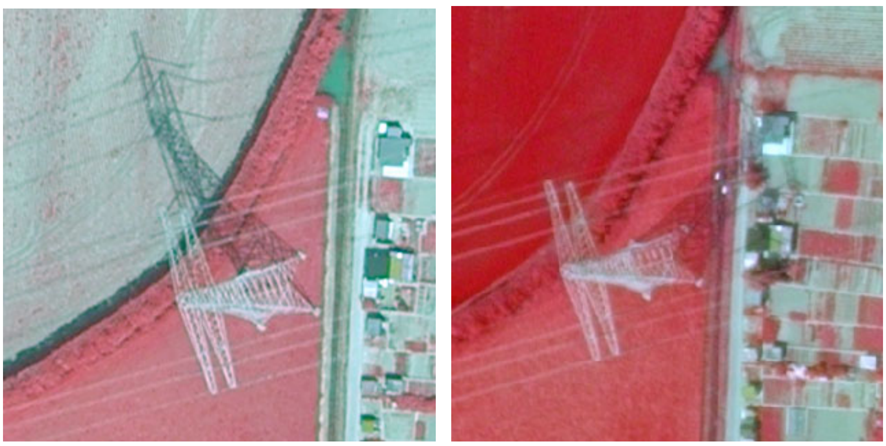

Figure 5: Shadows in different directions due to sun angle differences

CONCLUSIONS

This paper presented the results of the first phase of the Dutch *Mutatis Mutandis* project. This project aims at sharing information on changed geo-information between different agencies that all collect data for the entire country. Both data providers and end users were interviewed to outline their requirements and expectations.

We found that all participants agree that sharing information will lead to higher data quality, and that cost reduction is a welcome though not conditional side-effect. A web service where both providers and end users can upload their detected changes seems a feasible method to facilitate the exchange of change information. To the providers a non-validated web service seems sufficient, yet the end users prefer a validated service, where the uploaded information is checked before it becomes available to other users.

Besides the feasibility of the web service, the benefits of such a data exchange were estimated. For the non-validated web service the benefits over a five-year period would add up to 5.6 M€. For the validated web service this would be 31.3 M€ without and 61.9 M€ with governmental benefits.

The next phase of the project will aim at developing an object-oriented change detection system. Three types of changes can be expected in remote sensing imagery: 1) conversion of objects, those changes are relevant to the data providers and end users, 2) modification of objects, those changes are irrelevant, and 3) differences caused by technical differences between the images.

We studied two photos of the city of Dordrecht in the Netherlands. All three categories of changes are present in the photos, although the first category does not show a high frequency, whereas the second category seems omnipresent. Given the nature of the third category it will be relatively easy to take care of these changes even though they cause false alarms. The challenge of the future method will lie in the recognition of irrelevant changes.

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