

DETECTION AND RECOGNITION OF CHANGES IN BUILDING GEOMETRY DERIVED FROM MULTITEMPORAL LASERSCANNING DATA

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ABSTRACT:

The work presented is part of a project that aims at change detection in urban areas after strong earthquakes. Detection and classification of these changes are used to recognise building damages as an important information input for a disaster management system based on GIS techniques. Airborne laser scanning data was chosen for this approach, because of specific advantages like data acquisition of large areas in relatively short time or extensive independence on weather and lighting conditions. Modifications are detected by comparison of digital surface models (DSMs) acquired at two different dates (t_1 and t_2). An analysis of solely a differential DSM ($DSM(t_1) - DSM(t_2)$) would lead to ambiguities, e.g. attachments or modifications of buildings could not be related to the affected buildings. Therefore, firstly a segmentation procedure based on a region growing algorithm is used to generate separate 3D objects. For each segment object-oriented features like border gradients or shape are extracted to classify into 'building', 'vegetation' or 'terrain'. After elimination of all non-building objects, the correspondence between the objects of the two laser scanning data sets has to be determined. At this step, new and teared-off buildings are extracted. The remaining 3D objects have to be controlled in terms of significant elevation changes and thus classified into 'not-altered', 'added-on' or 'reduced'. First results in test area 'Karlsruhe' (approx. 8km x 2km) will be presented.

KURZFASSUNG:

In diesem Artikel werden Teile der Arbeit eines Projekts dargestellt, das sich mit der Änderungserkennung in städtischen Bereichen nach schweren Erdbeben beschäftigt. Das Ziel des Projekts ist die Entdeckung und Interpretation von Änderungen an Bauwerken um Gebäudeschäden zu finden, da sie wichtige Informationen für ein GIS-basiertes Katastrophenmanagementsystem darstellen. Im Projekt werden Daten des flugzeuggetragenen Laser Scannings benutzt, da diese Sensoren bestimmte Vorteile aufweisen, z.B. schnelle Informationsgewinnung über große Bereiche oder weitestgehende Witterungsunabhängigkeit. Die eigentliche Änderungserkennung basiert auf dem Vergleich zweier digitaler Oberflächenmodelle (DOM), die zu verschiedenen Zeitpunkten erfasst wurden. Würde man ein reines Differenzen-DOM untersuchen, dann käme es zu Mehrdeutigkeiten, es könnten z.B. Anbauten oder Veränderungen an einem Gebäude nicht immer zu diesem zugeordnet werden. Aus diesem Grund werden zuerst 3D-Objekte mit Hilfe eines region-growing basierten Segmentationsverfahren extrahiert. Für jedes Segment werden Merkmale wie Randgradientencharakteristiken oder Formparameter bestimmt, aufgrund denen das Objekt den Klassen 'Gebäude', 'Vegetation' oder 'Gelände' zugeordnet wird. Danach werden die zu beiden Zeitpunkten aufgefundenen Gebäude auf ihre Überlagerung hin untersucht. Bei diesem Schritt werden Neubauten oder abgerissene Gebäude entdeckt. Die verbliebenen Objekte werden nun hinsichtlich signifikanter Höhenänderungen analysiert und dabei den Klassen 'unverändert', 'aufgestockt' oder 'niedriger geworden' zugewiesen. Erste Ergebnisse für das Testgebiet 'Karlsruhe' (ungefähr 8km x 2km) werden gezeigt.

1. INTRODUCTION

In this paper a method for change detection in urban areas is presented. It is focussed on changes of buildings which may be caused by planned, man-made modifications like rebuilding, extension, tear-off etc. or by natural disasters like strong earthquakes. To detect the latter ones is the main objective of a special project of the Collaborative Research Center 461 'strong earthquakes' (CRC 461, 2004).

Building damages are one of the most important input information for a disaster management tool to optimise rescue activities. Therefore, a system for data acquisition under hard

time restrictions and for large areas has to be found. Airborne laser scanning - which has matured to an operational system in the last years - was favoured for this special task. It provides 3D coordinates for every measuring point by recording slant range to the reflecting surface point (laser sensor) and spatial orientation of the sensor (GPS / INS). The advantages of this system are high point density, high elevation accuracy, fast data acquisition of large areas, automatic determination of the height values, high independence of illumination conditions and robustness due to most weather conditions. Therefore, the system can be used also during night time and poor weather conditions which is a very important aspect for disaster management. Fortunately, there is no influence of shadows on

data acquisition and analysis like it can be observed for aerial images. In contrast to aerial images laser scanning provides dense height data with a specific characteristic of the acquired data. For instance buildings - and most vegetation objects - are characterised by a series of significant gradients along their border lines. Modern laser scanning sensors are able to record data in two different modes, first and last pulse response, which leads to somewhat different appearance of 3D objects in the derived laser scanning data (Steinle & Vögtle, 2000), what can be used for a better analysis of the information, e.g. to detect deciduous trees.

In general, changes or modifications of 3D objects can be observed by examining changes of their geometry. Using laser scanning data, elevation differences inside or around a building area have to be detected and analysed for this purpose.

In this approach, changes will be detected by comparison of digital surface models (DSMs) of two different dates (t_1 and t_2). An analysis of solely a differential DSM (= $DSM(t_1) - DSM(t_2)$) would lead to ambiguities, e.g. attachments or modifications of buildings could not be related to the affected building. Additionally, changes of all other objects like trees, bushes, infrastructure devices etc. have to be excluded when intending to use this methodology in the context of a disaster management system where the task is to provide rescue measures for people being trapped in damaged *buildings*. Therefore, in a first step a segmentation based on a specific region growing algorithm is applied to generate separate 3D object areas. In a second step each segmented object has to be classified in order to exclude all non-building objects. After elimination of these objects, the correspondence between accordant building segments of the two data sets (at the dates t_1 and t_2) has to be determined by inspecting overlapping areas. Inside overlapping objects parts the DSMs of both dates are analyzed to classify the buildings into *not-modified*, *heightened* or *decreased*. Not overlapping parts are analysed in regard to new or teared-off structures.

2. LASER SCANNING DATA

The basis for the change detection procedure are laser scanning derived DSMs. Laser scanning is operational since approximately 10 years. It is a measurement technique using basically the reflections of an emitted laser light signal, produced by the aircraft-borne system itself, to determine the distance between the system and the measured point. On the aircraft, positioning and orientation sensors of high precision are installed in addition. Therefore, 3D coordinates of a measured point can be computed (more details see e.g. Wehr & Lohr, 1999).

Here, data acquired by the pulsed laser scanning systems TopoSys I and TopoSys II were used (see TopoSys, 2004). The measurements were carried out in last pulse mode and the measured points interpolated onto a regular grid of 1m x 1m grid cell size, i.e. digital surface models (DSM) of 1m resolution were produced.

A first flight over the city of Karlsruhe (south-west Germany) was carried out in January of 1998 using TopoSys I, another one in spring 2002 using TopoSys II. Both flights were carried out with an airplane in a flying altitude of about 800m above ground.

3. SEGMENTATION AND CLASSIFICATION OF 3D OBJECTS

For each of the two original data sets DSM (t_1) and DSM (t_2) a segmentation of 3D object areas has to be performed. In order to get exclusively 3D objects on the surface of the Earth - i.e. to eliminate the influence of topography - a so-called *normalized DSM (nDSM)* was determined for each data set. Therefore, in a rough filtering process, points found to reliably lie on the ground were extracted (e.g. Weidner & Förstner, 1995; Sithole & Vosselman 2003; Vögtle & Steinle, 2003) which can be interpolated to a digital terrain model (*DTM*). The resulting nDSM for each date can be calculated easily by subtracting this DTM from the original DSM.

A segmentation procedure is now applied to these nDSMs which is based on an adapted region growing algorithm. Because this application is focussed on buildings and their changes, the parameters of this region growing algorithm are chosen in such a manner that nearly all buildings are segmented but only few vegetation objects. Taking into account that a building has certain minimal dimensions, this process starts at a point (crystallisation point) in which neighbourhood n points (e.g. $n=5$ or $n=9$) exceed the minimal building height (e.g. 2.5m). Iteratively, new neighbouring points are added to this area if their height difference does not exceed a maximum acceptable value - defined for instance by the maximal slope of roof planes which may occur in urban areas, e.g. 1.2m (homogeneity criterion). Therefore, region growing automatically stops at object boundaries of buildings and higher vegetation objects.

Using these parameter values, nearly all buildings could be segmented in the used test site "Karlsruhe". A lot of vegetation objects with significant height texture were not segmented due to the restrictive definition of homogeneity criterion, a favourable effect for this application.

An extraction of object-relevant features is performed inside each segment area, e.g. amount of significant border gradients, height texture, first/last pulse differences, shape parameters and laser pulse intensities. These features are used to classify all segments into the main object classes *buildings*, *vegetation* and *terrain* (Vögtle & Steinle, 2003). Different classification methods based on *fuzzy logic* and *maximum likelihood* have been tested for this kind of data, in the case of fuzzy logic also different inference schemes like *Maximum*, *Minimum*, *Product* or *Weighted Sum* were applied. Our investigations show that over all classification rates of about 89% to 95% - dependent on the characteristics of different test sites - may be obtained (Tóvári & Vögtle, 2004).

Now, these classification results are used to exclude all non-building objects - in test site Karlsruhe mainly vegetation; due to a quite flat terrain surface no small terrain rise was included, e.g. rocks. The final result is an segmentation image where only building areas remain, each with an individual segment number, nearly all other objects are excluded; an example is shown in Figure 2. It is the result obtained for the scenery shown in Figure 1, where a part of a nDSM determined for the campus of Karlsruhe university is given in grey-value coded representation.

If reference data (e.g. previously created and verified 3D city models) are available for the first date t_1 - as it is the normal case for applications in disaster management - the change detection process for buildings can be started directly without this segmentation and classification step. In this case a

considerable disadvantage is that new buildings can't be detected which is essential for updates of existing data set like building layers in GIS or 3D city models.

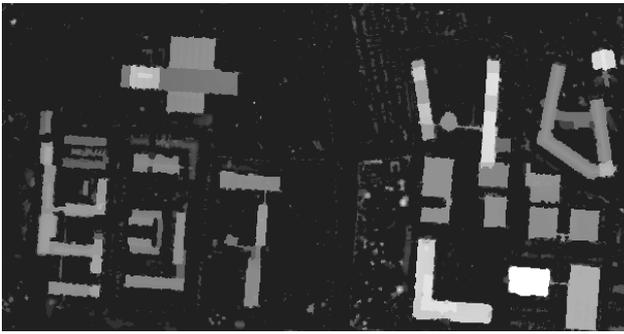


Figure 1: Grey-value coded representation of a nDSM (test site "Karlsruhe")

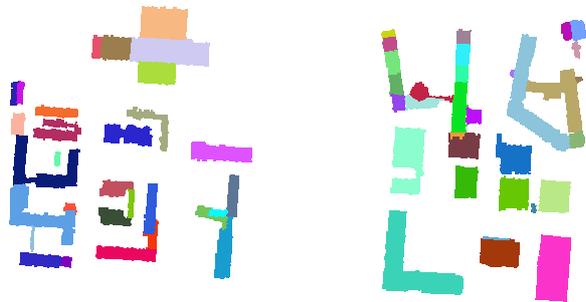


Figure 2: Segmented buildings of the scenery shown above, different segments have different colour

4. CHANGE DETECTION

The term *change detection* is used in lots of very different contexts. A major interest in change detection technologies exists in projects which aim at environmental monitoring tasks. In this field, the term is often used for methods capable to extract differences in the appearance of natural habitats at different dates, e.g. the spread and development of species occurring in forests (see e.g. Bhattacharyya et. al., 2002), alterations caused by human settlement activities (e.g. development of the city of Istanbul, see Altan et. al., 2002) or impacts of natural disasters (e.g. Maffra & Honikel, 2002). Most approaches do not concentrate on analysing single objects (e.g. single trees of a forest) but on indicating changed areas. Some approaches continue with a classification of the changes in the sense that the old and new state of these areas is classified, e.g. according to land use or occurring species.

In recent years, other applications of change detection approaches arose which are concerned with an object-wise analysis, focussing often on buildings. In contrast to the already mentioned change detection approaches, the task in these projects is not to analyse the usage or cover of a special area, but to rate the state of a special object at a special date in comparison to its state at another one. Above all, this means to observe its geometry (changes). Such information can be integrated in spatial databases for e.g. urban planning and management purposes (see e.g. Matikainen et. al., 2003;

Jung, 2004). Therefore, this is a kind of general, application independent data source. But it can be acquired and used for specific, present problems, too, e.g. disaster management tasks (compare e.g. Steinle et. al., 2001). The application can have implications on the used methodologies, especially the degree of automation, and the categorisation of occurring changes. Nevertheless, there exist three main groups of building states which are incorporated in most approaches: *new*, *missing* (or *not-confirmed*) and *not-altered* (or *confirmed*). Dependent on the specific application, these classes can be further sub-divided and other classes may be added.

For the project which is presented in this paper, the following five classes were defined:

- not-altered buildings
- added-on buildings
- reduced buildings
- new buildings
- demolished buildings

The approach developed in this project is *automatic, exclusively based on height data and object-based*, i.e. it analyses those objects extracted by segmentation and classification approach which was described in chapter 3. The change detection is carried out in three main steps:

- 1) extraction of buildings that can not be evaluated
- 2) extraction and further analysis of objects that do not sufficiently match with the objects at the other date to identify new, modified and demolished buildings
- 3) classification of the remaining objects into not-altered, added-on and reduced buildings

In the following, the individual steps are described in more detail.

4.1 Not-analysable buildings

In this work, data captured by TopoSys I sensor was compared to such of TopoSys II (chapter 2). As TopoSys I sensor is less sensitive than TopoSys II a number of deviations could be observed (e.g. Steinle & Bähr, 2002). One of these deviations is caused by the characteristic of the sensors when weakly reflecting material is hit. Using TopoSys II, such objects do not stick out in the derived DSM, whereas they are missing in DSMs computed on the basis of TopoSys I measurements (Figure 3 to Figure 6 show an example).

In the Figure 4 - Figure 6 grey-value coded (visualisations of) DSMs are shown, which were computed on the basis of laser scanning data. The brighter the colour, the higher the regarded region. Black coloured areas show lack of measurement data. It is obvious, that the dark roofed building was only partly resp. nearly not registered by TopoSys I sensor.

This effect is related to the system's ability to differentiate between the backscattered measurement signal and background noise. TopoSys I did not have a receiving unit capable enough to register the poor pulse intensity scattered back by the roof in the example, whereas TopoSys II shows a significantly higher sensitivity.



Figure 3: Aerial photography of a dark roof

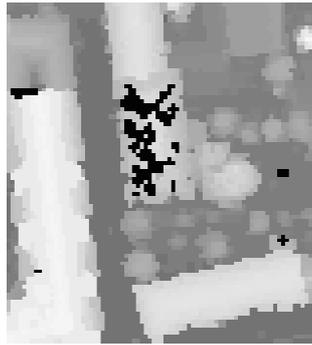


Figure 4: Same scenery in grey-value coded first pulse laser scanning DSM (TopoSys I)

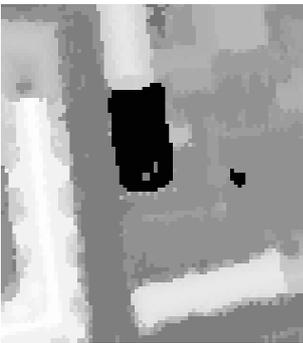


Figure 5: Same scenery in last pulse laser scanning DSM (TopoSys I)



Figure 6: ... and last pulse laser scanning DSM (TopoSys II)

Buildings containing large parts without data can not be regarded further in a change detection analysis as their state is not observable at one date.

Therefore, in a first step all building segments derived from laser scanning data were consecutively examined with regard to included no-data pixels in the according laser scanning DSM and were filtered out if a sufficient number of such pixels occurred. Here, the threshold was set to 4, assuming that no-data pixels may occur at elements on a roof, e.g. chimneys, but it can not be tolerated if they cover large parts of a building; on the other hand small buildings can consist of only 10 pixel (e.g. 2m x 5m ground plan), therefore, this value should not be exceeded.

4.2 New and demolished buildings

In a next step, the overlaps of the extracted building areas are examined. Based on the segments received from the DSM of the earlier date ($DSM(t_1)$), all pixels of a segment are analysed if they are part of a segment derived from the newer DSM ($DSM(t_2)$), too. Only if a segment of t_1 is found which has a certain percentage (e.g. 25%) of its ground plan area overlapping with segments of t_2 , it is kept for a further analysis. Otherwise, at all pixels the differences in between the both DSMs are checked. If a significant number of pixels - here the inverse percentage of the overlapping threshold is used (75%) - exceed a deviation tolerance value, which is introduced due to measurement accuracy and systematic deviations on slant planes, the segment is assumed to represent a *demolished* or *teared off* building. Otherwise the segment is also regarded for further analysis. The same procedure is carried out also on the segmentation result of the newer DSM and accordingly *new* buildings are found.

In the Figure 9 an example of the obtained results is shown. For an easier understanding the scenery is shown in two aerial images (Figure 7 and Figure 8), which were acquired approximately at the same time when the laser scanning flights took place, and, in Figure 9, the segments extracted from DSM acquired in 2002.



Figure 7: Aerial Photography captured in 1997



Figure 8: ... same scenery photographed in 2001



Figure 9: Result of the existing object analyses step of the change detection methodology; light grey: building segments for 2002 DSM, darker grey: new building, dark grey: demolished building

It can be observed that in the upper right corner a new building was detected, whereas in the lower image part a tear off was recognised. In fact, the complex of three buildings in the lower image part was entirely destructed and (partly) rebuilt. But as the building at the right part of the complex was almost identically rebuilt concerning its shape and height, nearly no changes were detected; only a lower part (and therefore considered as a segment on its own) originally surrounding the building in 1997 is lacking now.

4.3 Modified and confirmed buildings

The segments not yet classified in this process are assumed to be either *unchanged* or *modified*. Inside the ground plans of the remaining segments, i.e. those segments not yet classified as not-analysable, missing or new built, the according parts of the DSMs are extracted and the elder data is subtracted from the newer one. The resulting height difference image is filtered using the *opening operator* of mathematical morphology, i.e. an erosion with a consecutive dilatation is performed (e.g. Haralick & Shapiro, 1992), regarding occurring height differences as foreground values. The purpose of applying the opening methodology is to remove single, isolated pixels or small group of pixels with height differences. This is because they often represent small objects on the roofs tops, e.g. chimneys or small dormers, or differences occurred due to arbitrary measurement deviations.

The remaining (groups of) pixels are then classified according to the type of height differences. Three classes are used:

- height difference inside the tolerance range
- positive height difference (heightened)
- negative height difference (decreased)

Only segments containing pixels classified into the last two classes are further analysed, the others are considered unchanged.

For each segment, as well for those linked to t_1 as those of t_2 , the dominating difference type is determined. If both classes occur in almost the same amount inside the segment, it is not classified; then only the altered parts are classified accordingly, i.e. such segments contain different classified parts. In all other cases, the whole segment is classified according to the dominating differences type, i.e. either as *added-on* or *reduced* building.

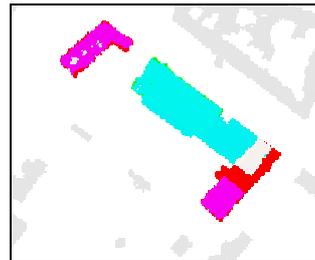


Figure 10: Reduction and add-on at building ensemble; the large part in the middle was increased, the others reduced

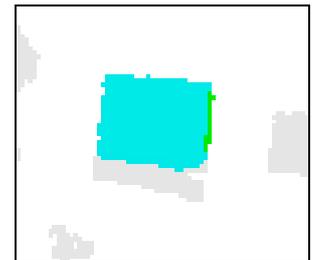


Figure 11: Building appearing heightened

In Figure 10 a result is shown obtained for a building ensemble (segments of the newer data set are laid beneath in light grey). The middle part was heightened, whereas the surrounding parts were decreased. In the lower right part a large building was partly teared-off; the one in the middle was extended so that it now covers a part of the former ground plan of the reduced one. As the change analysis is carried out for segments of both dates separately, a decrease (inside the ground plan of the elder) as well as an increase (of the newer) segment can be determined at this location, visualized by mixed colours at the most right corner. Such, the kind of alteration can be understand better.

Figure 11 is the representation of a building which was found to be heightened (by one floor). In fact, at this location a building was teared off and a new one erected, but exactly inside the old ground plan and equal shaped. Only a roofed entrance area was added, which appears as a bar directly beneath the building. The classification result is as far correct as another result can not be obtained regarding solely the height data. For a more precise rating additional knowledge besides the laser scanning data would be necessary.

5. CONCLUSIONS

The work presented in this paper is part of a project that stands in the context of a disaster management tool. The projects task is to provide fast and reliable information about the damage state after strong earthquakes. Regarding this, the presented approach is a first attempt to detect buildings likely to be damaged.

The methodology is based on laser scanning derived DSMs and it showed to be capable to reliably rate occurring buildings changes in some (rough) modification classes solely based on height data. New built and teared-off buildings were found correctly in the test area as long as they were not merged with

other buildings into one segment during the building extraction step. Otherwise, the segment was found to be modified. All the not-altered and modified buildings were detected correctly, too. Only the both groups of modified buildings - *added-on* and *reduced* - contain ambiguities in the interpretation of the received results. It showed that the approach to rate all segments separately, i.e. the ones obtained from the elder DSM independently from those received analysing the newer DSM, already helps to interpret the majority of changes correctly. Nevertheless, the method can not provide the full information necessary in the context of disaster management. But it helps to extract those buildings which possibly undergone a damage by indicating them as *reduced*. Such buildings can then be analysed by a more sophisticated methodology, e.g. based on extracted CAD models, which therefore needs more processing time, too. As disaster management is a time-critical task, a prefixed fast filtering of the data, like the method presented, makes sense.

Besides the application in disaster management, the results obtained using the approach can be used for lots of other purposes, too. As the object-based approach allows to detect changes better than a simple subtraction of DSMs, it could be used e.g. for a nearly automatically update of spatial databases in urban environments.

Significant improvement of the method could be achieved by applying methods to avoid merging several buildings into one segment. This could for instance be done by introducing a segment splitting methodology based on a simultaneously comparison of the segments from both dates in conjunction with the both DSMs.

To improve the information stored in a spatial database of urban areas, the buildings found to be unchanged could be used for an improvement of the information already stored in the database. For instance, a 3D-modelling of buildings could be applied for several dates independently and the results merged with the already stored 3D information to consecutively improve the models accuracy.

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