UPDATING GIS BY OBJECT-BASED CHANGE DETECTION

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ABSTRACT:

Today with the situation of rapidly emerging of high resolution earth observation data by optical and microwave sensors there is a growing need for efficient methods to derive, maintain and revise land cover data at various scales by regional, national and European authorities. Main drivers are recent and upcoming European directives and initiatives, which contain increasingly spatially differentiated monitoring and reporting obligations in agriculture, environmental protection and planning, water management and soil protection. This paper focusses on part of a current research project named DeCOVER, namely the change detection which is used to identify candidates of change in land-use (LU) or land-cover (LC). Within this project a consortium of eleven partners with co-funding from the Federal Ministry of Economics and Technology via the German Aerospace Center (DLR) an attempt is being made to develop and demonstrate an innovative and cost-efficient geo-information service aiming in the establishment of a national landcover data base to serve different monitoring and reporting obligations of official users to the EC in the fields of agriculture, environment protection, water management, soil protection or spatial planning. This data base is intended to serve with its structure as a GIS source for ontology-based semantic interoperable methods and data to meet also the requirements of other national data bases like ATKIS, CORINE CLC and BNTK.

The planned implementation of DeCOVER includes a concept for an object-based change detection attempt to efficiently update existing geo-spatial data which is described in this paper. The change information needed is derived from recent satellite images using automatic image processing and analysis. The conceptual idea includes both, manual (applying visual interpretation) and automatic image analysis steps resulting in a change layer, which highlights those areas or objects which are suspect for change and gives an indication of the direction of change.

This investigation uses multitemporal remote sensing satellite data of a spatial resolution of approximate 5 m to be comparable to the planned German RapidEye system and the existing TerraSAR-X data. Different pre-processing steps have been implemented in order to avoid seasonal effects or changes due to different imaging conditions, such as atmospheric conditions, different sun angles, etc.. However not always ideal imaging conditions can be found which result in change indications, like shadows which becomes more dominant with increasing image resolution. Further pre-processing includes an automatic haze reduction and a shade correction using an appropriate DTM. Image co-registration and automatic cloud and shade-of-clouds detection is performed. Additionally, a priori knowledge of potential change for the object classes used in the GIS of concern is used as input to control the subsequent image processing.

The concept of the change detection starts by setting up a focusing step to selectively initiate the following steps only for those objects which are considered as *changed*. Thereafter all changed objects are classified either visually (manually) or by an automatic procedure depending on the type of change detected. The decision which classification procedure is used depends on a transition-probability-matrix which indicates for each class the degree of likelihood of possible and impossible class-transitions respectively in combination with a table of available classification operators which can be applied to validate the predicted change. The transition-probability-matrix is generated manually and contains assumed possible changes from one class to another. If an automatic classification is indicated, the procedure then consists of two parts: First it is evaluated if the object's geometry is changed or if the object is changed as a whole. If a change in geometry is detected, the object of concern has to be re-segmented and re-classified. If not, the object has to be re-classified only. If a manual classification is indicated, changes will be mapped respectively. At the end the results of the visual/manual classification and the automatic classification are joined into one change layer, which holds for each changed object besides its change indication information, the objects' historical classification and its new classification. This layer can then be directly used as input for updating existing GIS databases.

This paper concentrates on the first part of the process chain, namely the focusing module. The focusing module has two tasks: First, objects have to be found in the GIS data which are affected by change. Second, the focusing module has to decide, whether the changed objects subsequently can be processed automatically or must be processed manually.

Different change indicators are implemented based on a comparison of the input satellite data of two different dates. These indicators in combination with a transition-probability-matrix are used to limit the new possible classes and control the subsequent re-cursive processing and use of operators to verify the indicated changes according to the sorted probabilities of change. The obtained results of the proposed object-based change detection process chain are compared to change-detection results obtained by completely visual interpretation. Finally all results are assembled to a resultant change indication map.

1. DECOVER BACKGROUND AND CONTEXT

In the context of GMES (Global Monitoring for Environment and Security), a joint initiative of European Commission and European Space Agency, several services are developed to provide spatial information in support of the monitoring and reporting obligations of European directives (Overview at www.gmes.info, Example Water Framework Directive Dworak et al 2005). These implementations take place with strong participation of German authorities, researchers and service providers. Current developments at the European level support a new European-wide land cover data set (Core Service Land Monitoring). This data set must be seen as a European consensus and will solely contain thematic land cover data information supporting European reporting obligations. Its geometric and thematic resolution will only partly support national and regional needs. DeCOVER (Büscher, et al., 2007) will complement and extend these developments at the national and regional level for German users.
A set of geo-information services has been designed to support national and regional users in their monitoring and reporting obligations. The DeCOVER service concept is divided into core and additional services. The DeCOVER core service has two main focal points. First, the provision of national harmonized land cover data supports the German spatial data infrastructure (GDI-DE) in providing selected and validated geo-information and second, the development and application of change detection and interoperability methods to sustain existing data bases (namely ATKIS, CLC and BNTK). The project is co-funded by the Federal Ministry of Economics and Technology (BMWI) via the German Aerospace Center (DLR) and implemented by a consortium of 11 partners (see Table 1) each using its own expertise and specialized skills.

Partner	Expertise
EFTAS GmbH	Coordination, Agriculture
GAF AG	Validation, Forestry
DELPHI IMM GmbH	Interoperability, Link to INSPIRE
IPI, LUH	Innovation, Quality Control
Infoterra GmbH	Spec. Core Service, Economics, Link GMES
RapidEye AG	Implement. Process. Chain
GDS GmbH	Change Detection, SAR-Appl., Urban Areas
Definiens AG	SW support,Object oriented Segmentation. & Classific. of Water Areas
RSS RemoteSensing Solutions GmbH	Nature Landscape conservation
Jena.Optronik GmbH	SAR-Optical Co-Registration
DLR Assoc. Partner	Support. Urban, SAR-Proc.

Table 1: Consortial Partners, Expertises and Skills

The overall structure of the project is shown in Fig. 1. In a coordinated attempt the processing (segmentation & classification of the satellite data is being done according to rules and directives as demanded by European and National directives and policies. Much effort has been put into the consideration of user requirements, which directly influence the service definition and design of the DeCOVER database and its production chain which has a strong feedback to user demands. Methods

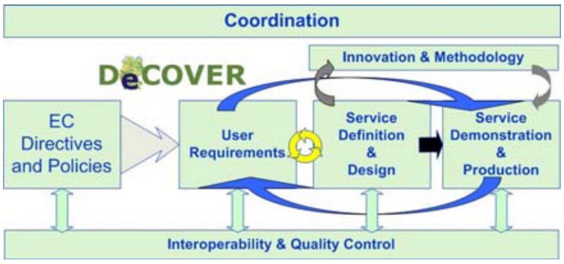


Figure 1: DeCOVER Organisation

developed and strategies used are being implemented for the creation of the core service and have direct impact to the processing chain, quality control and data revision, considering at each stage the specification and standards as demanded by the interoperability task. An initial user requirement analysis has shown real synergies between (thematically) different user needs. Parallel to the user requirement analysis, interoperability potential between the identified land cover classes has been analyzed, to optimize synergies between existing data sets and newly collected information. The currently tested core-service object catalogue includes 39 land cover (LC)/land use (LU) classes arranged in hierarchical order. The detailed object catalogue and mapping guide can be found in the user portal of the DeCover homepage (http://www.decover.info/).
There are three major areas of innovative research and development in the project, where methodologies are developed, namely
- the area of semantic interoperability
- change detection
- data fusion of optical and SAR images
In the following this paper will focus only to the second part, the change detection.

2. CONCEPT OF DECOVER CHANGE DETECTION

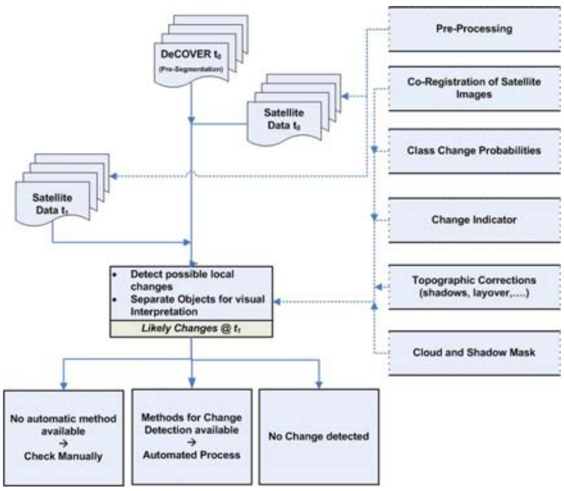
2.1 General

Change detection (CD) algorithms can be classified either into the comparison of classes following an interpretation at different dates (post-classification) or to image differencing (Singh, 1989). The former focuses on the comparative analyses of independently produced interpretations from different times, the latter comprises simultaneous analysis of multitemporal data. Because a second classification of the whole area results in costs, that are far too expensive for most of the users another procedure is envisaged here. CD in this case is regarded not as a change mapping but rather as a "notification/indication" of change with a possibility to indicate geometric and attributive change occurrences (i.e. class transition). It relates to objects as part of an existing database but compares two images at different dates on pixel level, giving a pixel-based indication of LU/LC change. Methods for the comparison of images from different dates may be grouped into those which use univariate image differencing alone (Singh, 1989, Fung, 1990), methods to compare vegetation properties like NDVI or Tasseled Cap Tranformations (Richards, 1993), or change vector analysis (Lambin, 1994, Bruzzone et al, 2002). A comprehensive overview of existing pixel based techniques, their advantages, disadvantages and resulting accuracies is given by Lu et al, 2004. Relating these pixel-based indications to objects means, that an approach for integration and validation of the indications is needed. There are several ways to implement such a procedure as has been shown by different authors (Schöpfer, 2005, Busch et al., 2005 and Gerke et al., 2004). Because users of DeCOVER prefer some type of a “change notification”, which might also be useful for their specific application, like updating of user operated databases (i.e. ATKIS) by proprietary techniques the following attempt has been made to set up a framework for CD.

2.2 The Concept of Change Detection Workflow

2.2.1 The Focusing Module

A focusing module has been designed in close cooperation between the company GeoData Solutions (GDS) and the Institute of Photogrammetry, University of Hannover (IPI). It is a central part of the total CD-concept (see Section 2.2.2) and applies image differencing. Steps of pre-processing, necessary to render the two images comparable in both the spatial and spectral domains are included. Fig. 2 shows an outline of the focusing module.



Fgure 2: The Focusing module

Concerning the spatial domain the images have to be co-registered, which is critical, considering the combined use of optical and SAR-data or using high resolution optical satellites with different viewing angles. A “registration noise” is obvious in looking at the indicator images as of section 3, where even though advanced techniques for co-registration had been used, differences from different looking directions become visible. Changes in light and atmospheric conditions between both observations may be a potential further source of error. Although atmospheric corrections as well as image normalization is performed and cloud and shadow masks are generated in the processing chain, still the appearance of shadows at buildings in the high resolution data (IKONOS, Quickbird, SPOT5) is apparent.
The focusing module computes the pixel-based CD indicators and compares on the given initial object level if a class change is observed or not. As the difference image is assumed to be normal distributed, all pixel belonging to the +/- 0.1 quantile are considered to be change pixel. Because a crisp threshold is very often not satisfactory a new fuzzy approach is proposed (see 2.2.2). At the moment spectral differences, PCA, Texture and IHS-differences (see Fig. 3) are investigated but many more may be applied.
The data used in this work consists of two IKONOS multispectral images of May 28th, 2005 and April 16th, 2007 resampled to 5m resolution. Concerning the image dates it is obvious, that many changes with respect to phenology can be expected.
It turned out that using IHS-Difference indicator between both dates overestimates apparent changes to a certain extent. This is especially true for

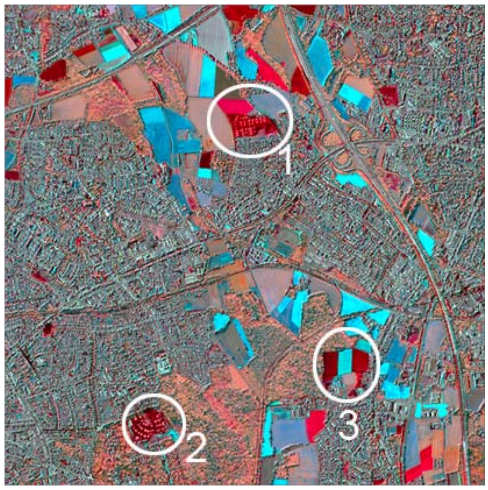
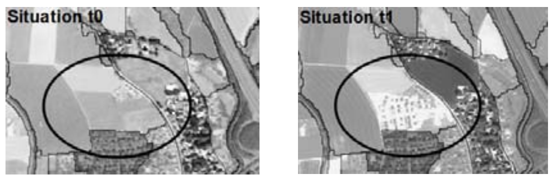


Figure 3: IHS-differences reflecting vegetation changes

vegetated areas, but color (1 to 3 in Fig. 3) can be used as an indication of change from/to vegetation cover, i.e. vivid red indicates a change from vegetation cover to bare soil, vivid blue from bare soil to vegetation cover. In addition by looking to the settlement areas it can be seen that shadow (because of different sun angles and different look angles at image acquisition) plays an important role. It can be noticed too, that a light pink tone accounts for the different image acquisition dates. For built up areas the texture information (Gimel’Farb, 1997) proved to give the best results. However the results shown in section 3 do yet not include the IHS tests.



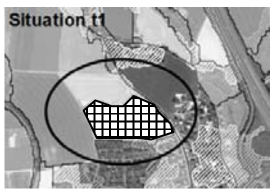


Figure 4: changes from agriculture to settlement as indicated by the Gimel’Farb operator for area 1 of Fig. 3

2.2.2 From Pixel to Object Change Indications

Once the change indicators have been computed, they are spatially combined before they are compared to the t_0 reference map (i.e. the existing database). One way of combining is the modification of a procedure which has been used by Earth Satellite Corporation, named Cross-Correlation -Analysis (Koeln et al., 2000). In this method class boundaries from the older thematic map separate image pixels into distinct class zones. Within these boundaries the pixels as of a new unsupervised classification are validated using a multivariate z-statistic. This idea has been adopted within this project using the old database as reference and computing within the object boundaries the Z-Value from a stacked (multiband) indicator image:

$$Z_t = \sum_{i=1}^{n} \left(\frac{r_i - \mu_i}{\sigma_i^2} \right)^2$$

with:

$n = $ *Number of features (indicators) used*

$r_i = $ *feature value of band i*

$\mu_i = $ *mean of band i for the segment from period* $(t-1)$

$\sigma_i = $ *s tan d.dev. of band i for the segment from period* $(t-1)$

According to Fig. 5 this value then is thresholded to indicate a change for the object selected. An á priori class transition probability matrice ($\mathbf{T}_P$), which has been set up beforehand and which reflects the probabilities of

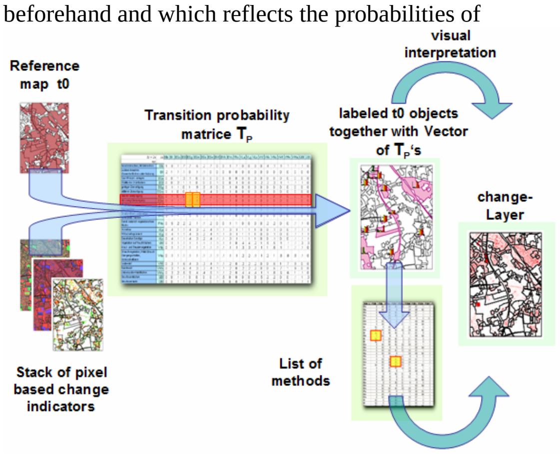


Figure 5: Use of Transition Probability Matrice

changes from one class to another is used to compute for the t_0 - objects a change vector consisting of a list of new possible classes sorted by the probability of change to that class.

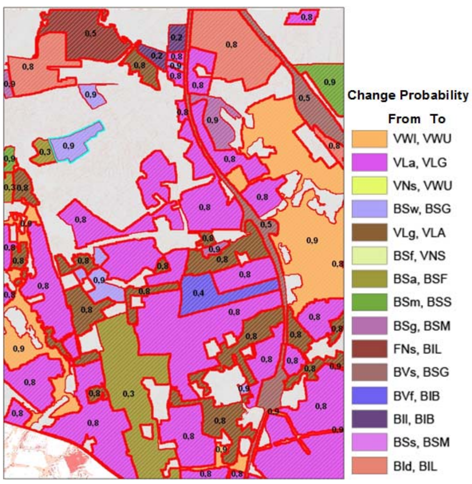


Figure 6: Change Probabilities and Target Classes as of $\mathbf{T}_P$

The focusing module then controls the way of further checking. If for the most probable class change an automated validation (re-classifier) exists it is applied. If no automatic method exists the object is labeled for further visual interpretation. If the first (most probable) change cannot be verified the next class out of the $\mathbf{T}_P$-vector is tested, until a change can be validated or the object remains labelled as unchanged. It should be noted, that the $\mathbf{T}_P$-matrice is a living document which is set-up by the experience of the DeCOVER partners first and then updated by the statistics of changes over time.

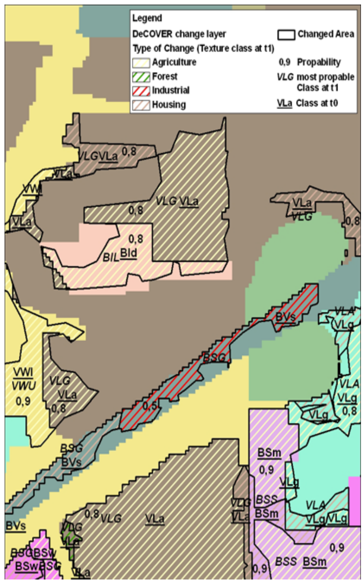


Figure 7: Change layer as output according to Fig. 5

As most of the operations are implemented in the Definiens Developer Software another way of combining the indicator images is planned, avoiding crisp thresholds for specific indicators. Thresholds are difficult to set and using more flexible fuzzy membership functions is desirable.

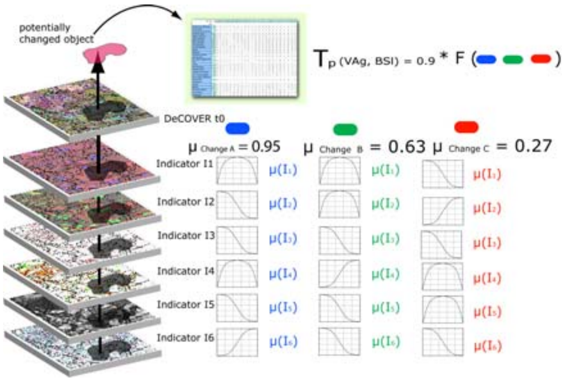


Figure 8: Using fuzzy membership functions and the $\mathbf{T}_p$ matrix

For a given object $\mathbf{T}_p$ contains the probability change vector which is combined with the membership functions $\boldsymbol{\mu}$ of possible transitions in a rule based manner to give the result as shown in Fig. 7.

The design of the total CD workflow is shown in Fig. 9.

Following the decision being made by the focusing module and the selection of automatic or manual (visual) interpretation methods the results are combined within the CD layer (Fig. 7). For all labelled objects, for which a change could be validated the presumed target class and the degree of probability is stored. If no exact change indication is possible, which for instance can happen in the case of very specific LU classes that only can be verified or classified by additional expert information, a flag is set. This flag serves as an indication for the experts in the processing chain, that this object is to be handled specially. Then the change layer is used in the processing chain for updating the changed objects.

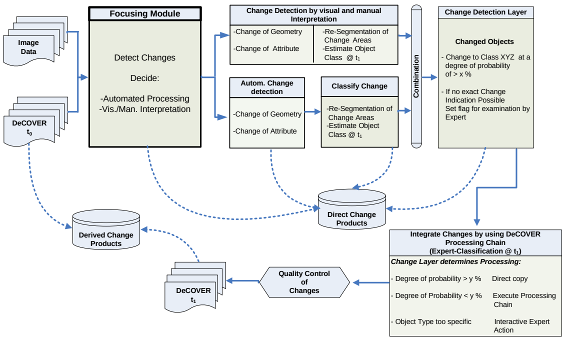


Figure 9: Design of the complete CD workflow

The intermediate results like those of the indicators can be stored as “Direct Change” products, for further use by the end-user. The current DeCOVER processing chain applies a sequential processing in the sequence of the main categories “Urban”, Water”, “Forest”, “Agriculture” and “Sub-natural open areas”. The identified new object type together with its change probability now is used to enter the sequence of classification operations at the appropriate position. This is followed by a quality control, which follows a procedure described by Hofmann et al., 2007.

2.3 Prelimnary Assessment of Indicators used

As reported above the focusing module computes pixel based indicators. Out of the variety of possible indicators (Lu et al., 2004) a selection is shown based on principal components (PCA), image differencing using the Pan channel and a 10% quantile (DP, see 2.2.1), texture like the Gimel’Farb-operator (GF), and the Haralik operators (variance H2 and dissimilarity H5).

The reference used for this investigation is based on a visual interpretation of the changes for DeCOVER objects out of Fig. 3 originating from 2005. A total of 877 objects belonging to the main object categories “Urban”, “Vegetation” (mixture of “Forest”, “Agriculture” and “Sub-natural open areas”) have been checked by using the 2005 object boundaries the visual change interpretation and the pixel-based indicators. A rating has been set up using the classification as shown in Table 2.

Change in	Reference true	Reference false
Indicator true	True positive (TP)	False positive (FP)
Indicator false	False negative (FN)	–

Table 2: Rating nomenclature used

Indicator	Object	TP	FP	FN	DP	BF
H5	U	3	56	10	23	95
	V	0	26	4	0	100
H2	U	20	45	11	65	69
	V	4	16	4	50	80
GF	U	5	61	2	71	92
	V	1	29	0	100	97
DP	U	7	64	0	100	90
	V	1	28	0	100	97
PCA	U	7	66	0	100	90
	V	2	24	0	100	92

Table3: Differences Vis. Interpr. to Indicators [%]

Calculating the results according to Table 2 allows to rate the indicators by using measures which have been described by Lin, 1998 and Müller, 2007. They use the Detection Percentage (DP) and the Branching Factor (BF)

$$DP = \frac{TP}{TP + FN} \quad ; \quad BF = \frac{FP}{TP + FP}$$

DP [%] reflects the amount of automatically indicated object changes, while BF [%] gives the percentage of found objects not belonging to the indicated type. The goal is to maximize DP while minimizing BF.

A problem with this assessment is that the reference which is used here is not a pixel-based one. So the results (Table 3) reflect more or less trends, than exact measures. There is a clear indication, that most differences belong to “False positive“. This is due to false detections at the pixel level because of shadows and look angles, as can be seen by looking to Fig. 10, which shows the difference of the indicator image and a simple morphological opening. These false indications can be avoided by integration using a threshold distance between detections or at object level taking into account a minimum object relevance area of for instance 0.4 ha.

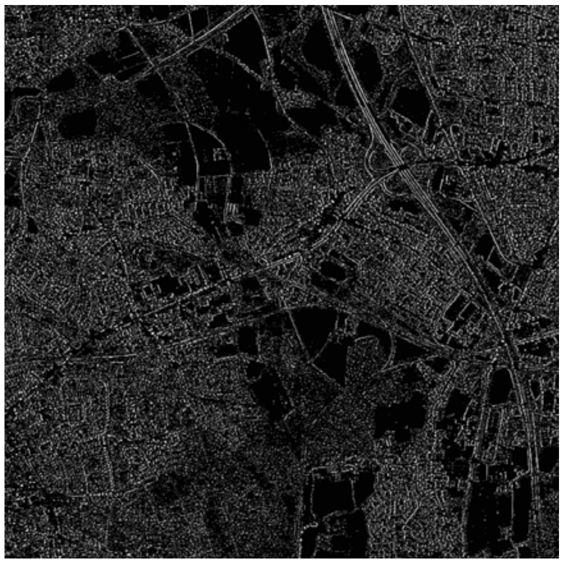


Figure 10: Difference of indicator image and its opening

In any cases the procedure as described allows a quick rating of the indicators, which presently for one indicator alone is very poor, but their combination or integration as described above may be comprising and is tested at the moment.

3. CONCLUSIONS

The paper pointed out some possibilities in using indicator images for highlighting areas of change. The results however show that no matter what single pixel based indicator is used, further integration to object or segment boundaries has to be done. Furthermore a combination of different operators possibly improves the results. Presently many other operators (especially the IHS and derivates thereof) are tested and the procedures for integrating their results to object level in combination with the class-transition probability matrice is developed and will be presented in future.

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