Lecture Notes in Electrical Engineering 520

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# Hybrid Landscape Change Detection Methods in a Noisy Data Environment

**Anton Afanasyev and Alexander Zamyatin**

**Abstract** The most used in practice land cover change detection methods by remote sensing data are considered. The approaches to the hybrid methods development those involve different methods of combining procedures and results are proposed. The results of change detection methods in different noisy data environment and intensities are presented. It is shown that an application of the hybrid methods for the change detection by data with different characteristics and noises is one of the most promising approaches to the land cover change detection, not only increasing the robustness of the results, but also simplifying the automated solution of this problem.

**Keywords** Remote sensing · Change detection · Hybrid change detection methods · Noisy data environment

## 1 Introduction

Change detection methods aimed to estimate accrued changes of some characteristics in considered area by time series data of remote sensing. Such methods are used in different tasks of aerospace monitoring that require detecting landscape changes (such as deforestation, urbanization, consequences of earthquake of flood) with a high reliability [1]. Research and development of new change detection methods and also ways of its improvement to get faster and more accurate results performing constantly [2–5]. Variety of different change detection methods and at the same time the absence

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of conventional techniques of selection the most suitable change detection method in each case leads to the problem that the methods are often chosen empirically without any proof in practice [2–6]. Despite the great attention of researchers to the problem of change detection [2, 7], there is still considerable potential for improving these techniques and increase their adequacy. One of the approaches that increase the value of such methods and simplifies finding a suitable change detection method in each case, is the combined use of several methods. These combined change detection methods called hybrid [3, 4].

Despite of active attempts to find optimal hybrid methods [8, 9], known results still have significant potential of improvement.

In addition, the adequacy of change detection methods result might have a significant defect because of different types of noise (i.e. natural or contributed by used photographical equipment) that may significantly affect the quality of the final result [2, 7]. Some distortions during significant change detection appear due to the difference in photographical equipment calibration, and also condition of survey, such as state of the atmosphere, sun angles, soil moistures and other factors. Also, distortion and noise can appear because of the failure of electronics and interference in the transmission of images [10]. However, in the above studies there is no proper attention on the effect of noise to the change detection results.

## 2 The Procedure of Change Detection

The initial data for a typical task of change detection are two multitemporal aerospace images (AI) of the same fragment of the landscape presented in the form of three-dimensional arrays $\mathbf{I}_1 = \left\{i_{1_{xyz}}, x = 1, \ldots, H, y = 1, \ldots, W, z = 1, \ldots, M\right\}$ and $\mathbf{I}_2 = \left\{i_{2_{xyz}}, x = 1, \ldots, H, y = 1, \ldots, W, z = 1, \ldots, M\right\}$, where $H$ and $W$—number of elements in rows and columns of starting AI, and $M$—the number of bands/channels of the images. Moreover, if $M = 1$ AI is panchromatic, with $M > 1$ is multi- or hyperspectral.

The process of change detection in the general case, typically, takes place in five steps:

(1) Formation $\mathbf{I}_1$ and $\mathbf{I}_2$ using preprocessing of AI (geometric, radiometric, atmospheric and topographic (if analyzed highlands) corrections) [11].
(2) Formation of the difference image $\mathbf{D}$ using one of the methods of change analysis. As a result of its using we obtain a three-dimensional matrix $\mathbf{D} = \left\{d_{xyz}\right\}$, in each its cell a value indicating the degree of change. In the case of $M > 1$ will require additional operation fusing the results from different channels.
(3) Determination of threshold $\tau$ separating value of changes as significant and insignificant. The value of the threshold $\tau$ is determined either by an expert or by using special functions, such as the method of the Otsu, Kittler-Illingworth, Kapur and other [12–14].

(4) Formation of the final matrix of changes $\mathbf{B} = \{b_{xy}\}$, wherein $b_{xy} = 1$ means the presence of significant changes (in the sense of a certain threshold or function) at a given point, and—$b_{xy} = 0$ absence thereof. Change matrix formed by applying a threshold function, wherein $b_{xy} = 1$ when $|\boldsymbol{D}_{xy}| > \tau$.
(5) Assessment of the change detection quality according to ground-based observations and other data. As a general rule, to evaluate the accuracy results, used parameters such as overall accuracy or Kappa index of agreement (KIA). If the ground truth data is absent this step could be skipped.

## 3 Change Detection Methods

There are many different land cover change detection methods and modifications thereof. Nevertheless, in practice, only some of them used much more often than other [10, 11, 15]. In our study, 7 of these methods are used: *Image Difference (ID)* [10, 16], *Image Ratioing (IR), Change Vector Analysis, (CVA)* [10], *Principal Component Analysis (PCA)* [11], method of Pearson (PRSN), *Chi-Square (CS)* and *Independent Component Analysis (ICA)* [17].

Result of image difference and ratioing methods is a three-dimensional array **D**, so to get final two-dimensional matrix **B** we need to combine the obtained result array by the layers in some way. In our case, were applied layer-merging methods to a matrix **D** and **B**. In the first case the strategy of *the average of the normalized values* ($ID_{norm}$, $IR_{norm}$) was used, that allows to use the threshold function only once and therefore, reduce the error of automatically determining the threshold. However, in case of significant deviations of **D** by layers may cause errors. In the second case for combining binary data were used three strategies: *disjunction* ($ID_{disj}$), *conjunction* ($ID_{conj}$) and by *majority* ($ID_{maj}$). These strategies allow reducing the number of type I and type II errors in different cases.

## 4 Experimental Study on the Applicability of Change Detection Methods

### *4.1 Statement of the Problem*

The experiments should identify what change detection methods (standard and hybrid) allow to obtain a more accurate result of the landscape changes, also with disturbances of different types in the input data. Set of AI with the different landscape-class structure will be used for experiments, this set characterized by varying parameters in a wide range—the average value, dispersion and average inter-channel correlation. As the data source is selected satellite Landsat ETM + with spatial resolution of 30 m. The size of the source data was 1700 × 1666, the number of channels -—7.

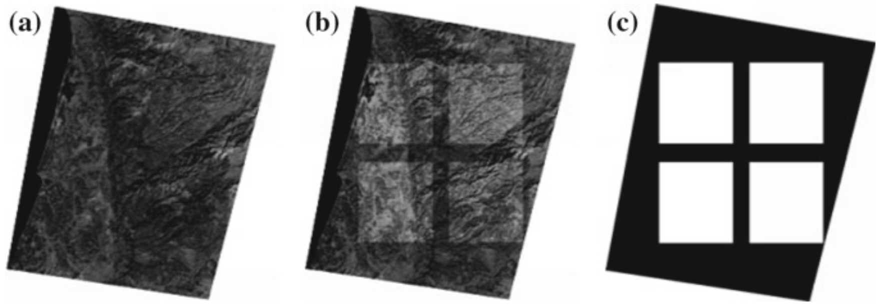


**Fig. 1** An example of the original image (**a**), the changed image (**b**), and the reference image with the known boundaries of the change areas (**c**)

To assess the quality of the change detection methods in the conditions of disturbance we will add the known values of changes, as well as noise. Formation of the initial test data pairs by adding artificial changes to data allow accurate assess of the executed difference analysis quality because reference image of changes a priori known. Using as input the original AI and altered AI with noise, we will apply standard change detection methods and their hybrid combinations. Rate the quality of the change detection methods results and its combination using reference images. When changes in $\mathbf{I}_1$ obtain $\mathbf{I}_1' = \{i'_{1xyz} = i_{1xyz} \cdot \gamma\}$, where $\gamma \in (-1, 1)$—the desired degree of change. Then find the reference matrix changes $\mathbf{B}^{\varepsilon}$ (Fig. 1).

Let's add noise of various types and intensity to the image $\mathbf{I}_1'$, and then apply change detection methods to the received data. The following types of noise are used: *the gradient*, *absolute change of the brightness*, *relative change of the brightness* and "*salt and pepper*". Distortion *absolute change of brightness*, *relative change of brightness* and *gradient* reflect the difference in the calibration of the sensor filming equipment as well as illumination and atmospheric conditions at the time of the shooting. Disturbance "*salt and pepper*" reflects noise that may appear due to hardware failures and interference while data transmission. The distortion *relative change of the brightness* is the multiplicative, additive remaining. Mathematical notation of each type of disturbance can be represented as follows.

*Gradient*: $i^{grad}_{xyz} = i'_{1xyz} + s_{xyz}$, $\mathbf{S} = \{s_{\text{xyz}}\}$—a matrix containing gradient. The main parameters of the gradient—maximum and minimum values: $g_{min}$ and $g_{max}$, $g \in (-20; 20)$.
*The absolute change of brightness*: $i^{up}_{xyz} = i'_{1xyz} + u$, where $u \in (-20; 20)$—set value.
*Relative change of brightness:* $i^{multi}_{xyz} = i'_{1xyz} \cdot m$, where $m \in (0.8; 1.2)$—set value.
"*Salt and pepper*": $i^{sp}_{x_k y_k z} = random(min, max)$, where *max* and *min* are maximal and minimal value of $\mathbf{I}'_{1_Z}$, $Z = 1, \ldots, M$, $x_k \in (1, \ldots, H)$ and $y_k \in (1, \ldots, W)$—random number, $k = 1, \ldots, n$, where $n$—the number of set, $S_{sp} = (n/(H \cdot W)) \cdot 100\%$—the proportion of the surface area with an noise, $S_{sp} \in (0; 50)$.

We will rate the quality of change detection results using the widely used criteria—Kappa index of agreement. Since the quality of the result depends essentially on the methods of threshold determining used in step №3 of change detection process, we will use the best threshold values, selecting it on the basis of the relate image. This will eliminate the influence of errors occurring at this stage, and allow more objectively compare of change detection methods.

We will use both a combination at the procedure level and combination on the result level. The following combination of change detection methods at the level of procedure: PCA-IR, PCA-CS, PCA-PRSN, PCA-CVA, ID-PCA, IR-PCA, CS-PCA. To combine the results using the following methods: a conjunction $\left(\mathbf{B} = \left\{b_{xyz} = b_{1xyz} \& b_{2xyz}\right\}\right)$, disjunction $\left(\mathbf{B} = \left\{b_{xyz} = b_{1xyz} | b_{2xyz}\right\}\right)$ and the addition of probabilities ($)

$$\left(\mathbf{D} = \left\{d_{xy} = d_{prob_{1xy}} + d_{prob_{2xy}}\right\}, \mathbf{D}_{prob} = \left\{d_{prob_{xy}} = \frac{d_{xy} - \min(D)}{max(D) - \min(D)}\right\}\right).$$

Perform the union of change detection methods results (including combinations at the procedure level) pairs is given of ways to get all the possible combinations. For each experiment, the original pair of images to be initial AI ($\mathbf{I}_1$) and each of the generated AI with modification and noise: $\mathbf{I}^{grad}$, $\mathbf{I}^{abs}$, $\mathbf{I}^{prop}$, $\mathbf{I}^{sp}$ for which we find the difference images $\mathbf{D}^{grad}$, $\mathbf{D}^{abs}$, $\mathbf{D}^{prop}$, $\mathbf{D}^{sp}$ with each change detection algorithms as well as combinations thereof. Then we find the matrix changes $\mathbf{B}^{grad}$, $\mathbf{B}^{abs}$, $\mathbf{B}^{prop}$, $\mathbf{B}^{sp}$, choosing the threshold parameter to maximize KIA.

## *4.2 The Results of Experimental Studies and Conclusions*

As the result of combining were obtained 650 hybrid methods. This is quite a large number for detailed visualization, so as an illustration we give only general diagrams and charts with the best results of the combined methods and simple methods of change detection.

As seen from the results (Fig. 2, the values less than 0.5 are not shown), KIA values vary for different methods within a wide range. In case of changing the brightness gradient is no obvious group of methods, which results show, far surpassing the others. But this disturbance has the least impact on the result. Obviously, the most

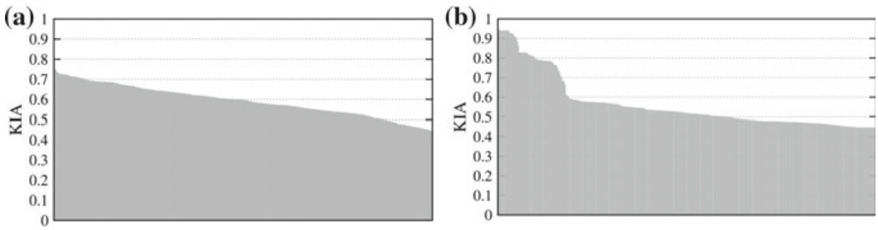


**Fig. 2** Assessment of the quality of change detection methods results and their combinations in terms of noises: **a** gradient, **b** “salt and pepper”

interesting are the methods, including their hybrid combinations showing the highest results. Consider the best results are obtained depending on the intensity of the added noise (Fig. 3).

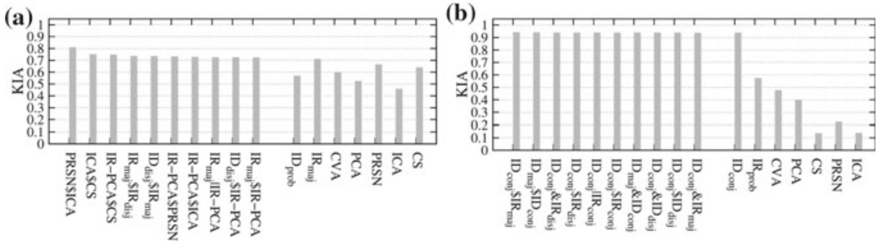


**Fig. 3** Examples of the quality assessment results for different types of noise: **a** the gradient, **b** "salt and pepper"

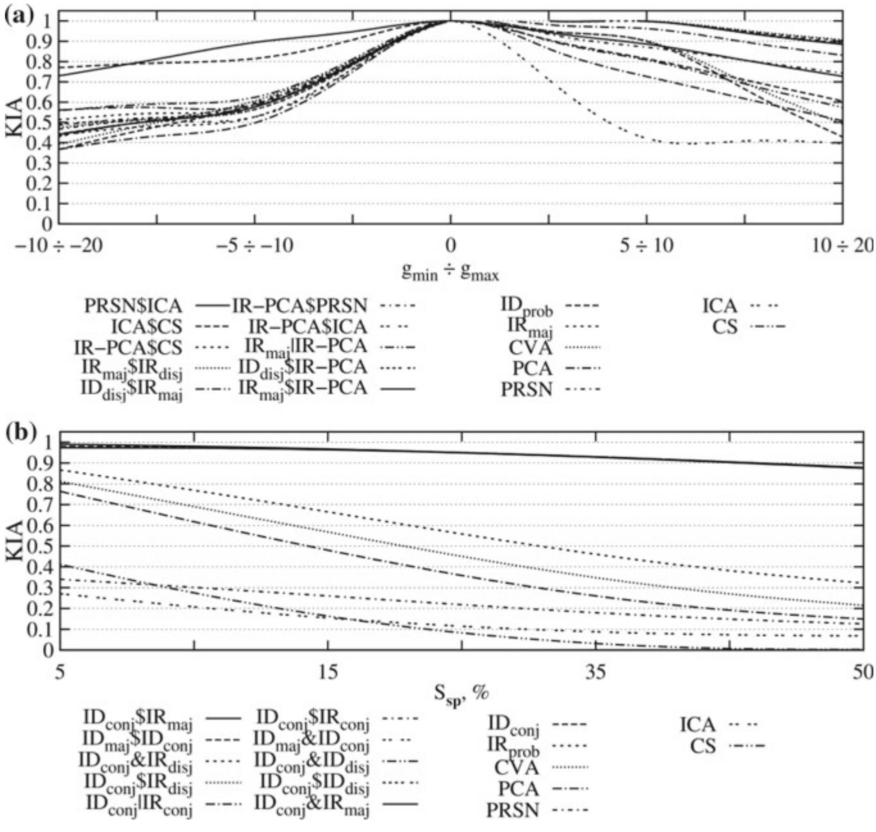


**Fig. 4** Results of quality assessment of the most stable hybrid change detection methods compared to simple methods for different types and values of noise: **a** the gradient, **b** "salt and pepper"

By the shown diagrams (Fig. 4), we can conclude that hybrid methods can be successfully used to improve the quality of change detection. Especially noticeable advantage of hybrid methods is detected for noise *gradient* (Fig. 4a) and the *proportional change of brightness* cases. Among the best hybrid methods most often occurs through the addition of the fusion probability. Only results with disturbance *absolute change of brightness* is more common union through disjunction.

According to results of the methods with different values of disturbance (Fig. 4) should be concluded the significant influence of disturbance value to the quality of the final result of change detection with most methods. It should also be noted that the hybrid methods increase stability of change detection. The best combination of methods is most often formed by addition of probabilities, only the results with the disturbance *absolute change of brightness* as a way of merger leads disjunction. However, there are different leaders among hybrid methods for different types of disturbance. So when disturbance is *gradient* two hybrid method (PRSN$ICA, ICA$CS) showed significantly better stability to negative values of the *gradient* as compared with standard methods and other hybrid methods. However, these methods have shown not the best results with a positive gradient. All the others shown hybrid methods demonstrated the best result (sometimes significantly) with a positive gradient over standard methods. With disturbance *absolute change of brightness* the best results was shown by hybrid methods using the method ID in various modifications and CS, whose results are combined through addition of probabilities or disjunction. With disturbance *proportional change of brightness* achieved significant improvement of change detection result using hybrid methods. In general it happened using the hybrid method of IR-PCA, whose results are combined with the results of many other methods by using the addition of probabilities. With disturbance "salt and pepper" the best results are obtained using the method $ID_{conj}$ at the union with the ID and IR methods of various modifications.

## 5 Conclusion

The existing methods and approaches to the problem of land cover change detection by remote sensing data are characterized by great variety and oriented on their using by experts, which significantly reduces the quality of the result while uncontrolled use, and complicates their automated application. The use of hybrid methods for the change detection is one of the promising approaches to the land cover change detection allowing improve the robustness of the results when using data with different characteristics and noise, as well as the possibility of simplifying the automated solution to this problem.

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