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A Comparative Study of Image Change Detection Algorithms in MATLAB

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Abstract

Change detection involves quantifying temporal effects using multi temporal data sets. When one is interested in knowing the changes over large areas and at frequent interval satellite data are commonly used. Results of the digital analysis to a large extent depend on the algorithms used. This study compares effectiveness of various change detection approaches implemented in MATLAB environment. Effectiveness being a function of study area, a typical south Indian agricultural village, Yagachi of Belur in Karnataka having visible change in land cover was pinned down for study. Techniques like Image Differencing, Image Ratioing, Change vector analysis (CVA), Tasseled Cap Transformation (TCT) and Principal Component Analysis (PCA) were used to detect the changes. The algorithms were implemented in MATLAB GUI so that a user friendly environment is created for testing different data sets. The efficiency and effectiveness of these methods in study area were compared using post classification and accuracy assessment. From the analysis it is seen that change vector analysis method excelled the general list. Prominent results marked best suits like Image differencing for detecting changes in biomass content and vegetation health; Principal component analysis for change in water quality and type of vegetation and Tasseled cap transformation in regeneration, deforestation, etc. Ratioing was unable to define changes effectively in study area. Similarly several results were obtained, showing best methods for tracking specific changes.

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Keywords: *Change detection; Algorithms; Remote sensing; ETM+; Matlab; GUI*

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1. Introduction

Change detection (CD) involves quantifying temporal effects using multi temporal data sets. When one is interested in knowing the changes over large areas and at frequent interval satellite data are commonly used. Results of the digital analysis to a large extent depend on the algorithms used. Many CD algorithms have been developed since the 1980’s and some of these are presented in review articles such as those by Singh (1989), Lu et al (2004) and in the textbook by Jensen (2005). Some authors combine traditional algorithms with use of GIS for conducting various spatial analyses on the data (Li and Yeh 2004; Yin et al. 2011).

Different techniques provide results that vary in levels of adequacy according to the specific application, for example (i) CVA excelled in an arid environments (Sohl 1999), temperate forest area (Nackaerts et al. 2005) and in transitional regions between tundra and boreal forest (Silapaswan et al. 2001); (ii) image differencing provide powerful interpretation of change in tropical region (Lu et al. 2005), urban environment (Ridd and Liu 1998) (iii) TCT in monitoring urban sprawl (Qian and Ban 2010) and (iv) post-classification presented the advantage of indicating the nature of the changes (Mas 1999). Thus the comparative effectiveness of various change detection techniques in different environments must be evaluated quantitatively to get knowledge about tried and tested procedures of change detection in a flexible mode. This helps in getting best results while monitoring changes in a specific environment.

The study was on efficiencies of the various change detection techniques on a typical south Indian agricultural village. The satellite images before and after commissioning of Yagachi dam with a gap of 7 years were used. Algorithms were coded in MATLAB environment.

The objective is to analyse multi temporal satellite image of an area which fulfill the definition of a typical Indian village using five CD algorithms: Image Differencing, Image Ratioing, CVA, TCT and PCA and to compare their efficiencies with post classification method and carry out accuracy assessment for different methods. Gratifying works to throw light on effectiveness of change detection techniques on Indian village environments have not been carried through yet. This study is demanded at this juncture.

2. Study area and data

The land area considered is Yagachi of Belur in Karnataka, India. It lies between latitude 13°8'18.36” and 13°13'15.81” N and longitude 75°41'24.34” and 75°51'16.33” E. The study area covers about 162.26 km^2. It is a typical agricultural area. Due to a visible prominent growth in land cover and land use, the Yagachi dam was commissioned in 2004 in the study area. The study was carried out using temporal satellite images of Landsat ETM+ taken on January 2003 and January 2011. Landsat images acquired are during the dry season, which enables us to ensure that the images are completely cloud free.

3. Methodology

The graphical abstract of the methodology used to compare the performance of the different change detection methods studied in this work is given in Fig. 1.

3.1. Image pre-processing

Pre-processing techniques are used to attenuate geometric and radiometric variations in orbital images (Borrego et al. 2001). In this work, the images from the sensor Enhanced Thematic Mapper plus (ETM+) were registered to WGS 1984 UTM zone 43N. Radiometric correction can be classified into three types: Radiometric correction of effects due to sensor sensitivity, radiometric correction for sun angle and topography and atmospheric correction. Radiometric correction to sensor sensitivity and to sun angle and topography was avoided owing to the fact that images were obtained from same sensor on same date and time of respective years. Appropriate atmospheric correction method has to be adopted to achieve a better detection of change. Here, atmospheric correction was done by histogram equalization.

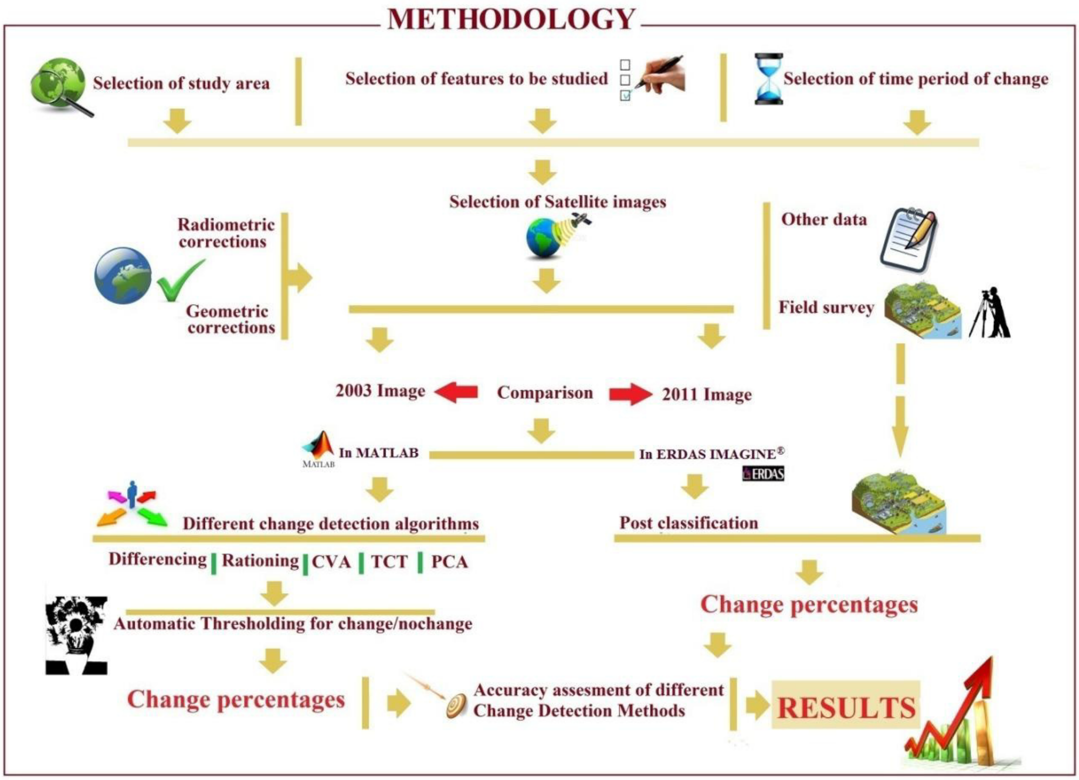

Fig. 1. Change detection methodology

3.2. Automatic thresholding

Most of the digital change detection techniques used in this study requires the selection of a threshold value in order to determine the change areas. The grayscale difference map is usually converted to binary form and thresholded at some pre-determined value to obtain a change/no-change classification. However, the threshold value is critical, since too low a value will swamp the difference map with spurious changes, while too high a value will suppress significant changes (Paul 1998).

An automatic thresholding algorithm based on an iterative threshold selection is employed in the study. At iteration n, a new threshold Tn is established using the average of the foreground and background class means. The iterations terminate when the changes |Tn – Tn+1| become sufficiently small (Mehmet and Sankur 2004).

3.3. Change detection algorithms

After the pre-processing stage was completed, five different change detection algorithms were applied to both images. These were: Image Differencing, Image ratioing, Change vector analysis, Tasseled cap Transformation method and Principal Component Analysis. The first three are pixel based methods while the last two are transformation based methods of change detection.

Image differencing:

Image differencing is used widely because of its simplicity to implement and interpret. It involves subtraction of the first-date image from a second-date image, pixel by pixel. In this study image differencing is employed with each of the reflective bands. The eight differenced images (Diff1, Diff2, Diff3, Difff4, Diff5, Diff6a, Diff6b, Diff7 and Diff8) are produced by subtracting the 2003 image from the 2011 image. A critical aspect of the image differencing method is deciding where to place the threshold boundaries between change and no-change pixels displayed in the histogram. Automatic thresholding algorithm is used to find out the threshold. Change mask is thus prepared for each band representing change and no-change regions. Mathematically,

Difference image, $$D(x) = I_2(x) - I_1(x) \quad (1)$$

Change mask, $$B(x) = \begin{cases} 1 & \text{if } |D(x)| > T \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Image ratioing:

Ratioing is considered to be a relatively rapid means of identifying areas of change. In ratioing two registered images from different dates with one or more bands in an image are ratioed, band by band. The data are compared on a pixel by pixel basis (Singh 1989).

Mathematically,

$$R(x) = \frac{I_1(x)}{I_2(x)} \quad (3)$$

If the intensity of reflected energy is nearly the same in each image then R(x) = 1, this indicates no change. In areas of change, the ratio value would be significantly greater than 1 or less than 1 depending upon the nature of the changes between the two dates.

Change vector analysis:

The change vector analysis involves two variables, the magnitude of variation and the angle of the change vector. The change vector is obtained by subtracting the images represented in vector form (Borrego et al. 2001). The first step of the CVA method is to find (Normalized Difference Vegetation Index) NDVI and (Bare Soil Index) BI values of both the images.

$$NDVI = (NIR - RED) / (NIR + RED) \quad (4)$$

$$BI = ((SWIR + RED) - (NIR + BLUE)) / ((SWIR + RED) + (NIR + BLUE) \quad (5)$$

where NIR, RED, SWIR and BLUE are the spectral reflectance measurements acquired in the near-infrared, red, short wave infrared and blue regions (band 4, 3, 5 and 1 in Landsat ETM+ image).

Change vector of each pixel includes two components NDVI and BI, which are the 2 axes in Cartesian coordinate system. The start point and finish point of the change vector are the locations of pixel in NDVI-BI space on T1 and T2 (T1, T2 are the acquisition date of images). The magnitude of vector represents the change intensity and the direction of vector represents the change dimension (Son et al. 2009). The concept of CVA is represented in Fig. 2.

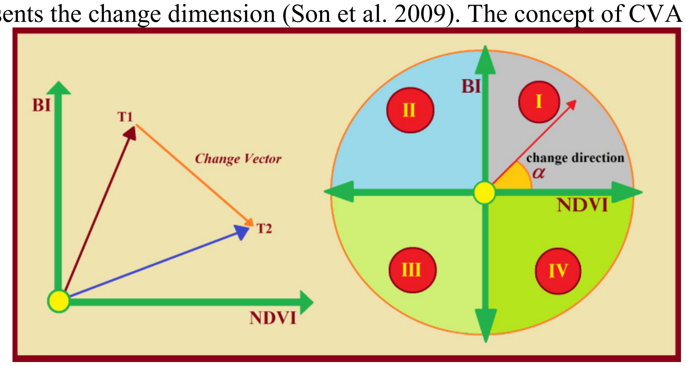

Fig. 2. Concept of CVA

The magnitude of change vector (S) and direction of change vector (α) are obtained by the following equations:

$$S = \sqrt{(NDVI_2 - NDVI_1)^2 + (BI_2 - BI_1)^2} \quad (6)$$

$$\tan \alpha = \frac{BI_2 - BI_1}{NDVI_2 - NDVI_1} \quad (7)$$

where, S is the length of change vector (Change intensity), α is the change direction (Nature of land cover change), NDVI1 and NDVI2 are the digital number of each pixel in the NDVI image at date 1 and 2, BI1 and BI2 are the digital number of each pixel in the bare soil index image at date 1 and date 2.

Change intensity image is divided into two levels. Level I is the area, that doesn't show changes. Level II stands for change areas. Change dimension is divided into four levels as described in Table 1. The dimension I shows the increase in both of the NDVI and BI index. The cause of this phenomenon is the moisture reduction between dates. Conversely, the decrease in both of the NDVI and BI index in the dimension III shows the water or high moisture land. The dimension II shows the increase in BI index and decrease in NDVI index. It is due to bare soil expansion. The dimension IV shows decrease in BI index and increase in NDVI index. The cause of this phenomenon is the chlorophyll increase between dates.

Table 1: Description of the change dimensions

Dimension of change	BI index	NDVI index	Description
I	+	+	Moisture reduction
II	+	-	Bare soil expansion
III	-	-	Water or high moisture
IV	-	+	Chlorophyll increase

Tasseled cap transformation method:

The tasseled cap transformation parameters of ETM+ imagery were used to calculate the Brightness, Greenness and Wetness components of each image. The Tasseled cap transformation coefficients derived for Landsat 7 ETM+ data by the EROS Data Center (Huang et al. 2002) are given in Table 2. Brightness is a weighted sum of all bands, defined in the direction of the principal variation in soil reflectance. Greenness is a contrast between the near-infrared and visible bands. It is strongly related to the amount of green vegetation in the scene. Wetness relates to canopy and soil moisture. The brightness, greenness and wetness indexes are obtained for both the images.

Table 2: Tasseled cap coefficients for Landsat 7 ETM+

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Wetness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388

ΔBrightness, ΔGreenness and ΔWetness are derived by calculating absolute difference of brightness index, greenness index and wetness index of 2003 and 2011 images respectively. These difference images were thresholded to obtain the change masks.

Principal component analysis method:

The principal components transformation is a linear transformation which defines a new, orthogonal co-ordinate system such that the data can be represented without correlation. A bi-temporal feature space is constructed by placing the two image vectors in the same space. The transformation is found from the eigen vectors of the covariance matrix of the original data. Each individual pixel is transformed by vector multiplication of its original vector and the eigen vectors, resulting in coordinates in the new space. The transformed data is re-arranged back into two images corresponding to the first and second principal components. The first component images contain no-change pixels whereas the second component images contain change information between the different dates.

3.4. Graphical user interface (GUI) in Matlab

Development of a MATLAB GUI for the algorithms studied increases the awareness of these algorithms and benefit the potential users. The user can input multitemporal images and can select the algorithm in order to get the result.

3.5. Post classification change detection

The method of change detection after classification is the most obvious method of detecting change. Post classification change detection was used as a cross-classification to determine ‘from–to’ change which enabled assessment of the five algorithms. Supervised classification was used to extract land cover information of the study area. ‘Maximum likelihood algorithm’ was used for the classification. This was done in ERDAS IMAGINE® software. Study area was delineated into 8 land cover types. Field survey coupled with Google earth images and land use land cover map obtained from ‘Bhuvan’ (http://bhuvan-noeda.nrsc.gov.in/theme/thematic/theme.php) were used for the identification of land cover types. The study area consists of agricultural cropland, agriculural fallow land, agricultural plantations, barren land, built up land, forest, shurbs and water bodies. Table 3 gives the comparative study for the area covered by different land cover classes after doing supervised classification.

Table 3: Area Information

Class name	2003 area in m^2	Area in %	2011 area in m^2	Area in %
Water body	2603605	1.60	4945502	3.05
Agricultural plantation	18093171	11.15	23031866	14.19
Agricultural cropland	32592494	20.09	59000717	36.36
Agricultural fallow	66730401	41.13	31186182	19.22
Barren land	6209973	3.83	2369896	1.46
Builtup land	1832638	1.13	7156309	4.41
Shrubs	3142377	1.94	559400	0.34
Forest	31051841	19.14	34006628	20.96
Total area	162256500	100.00	162256500	100.00

4. Results and discussions

It is seen that the change images produced have different change percentages and different accuracy levels in detecting changes as seen in Table 4.

Image differencing algorithm applied to the study area and its accuracy assessment revealed that, differencing could be well used to detect the changes in band 4 (near infrared band), which is good for mapping shorelines and biomass content. Accuracy check for other bands gave accuracies more than 65 %, with moderate kappa values, indicating that they can also give average idea on changes while performing image differencing. During our study image ratioing gave poor results. Ratioing was unable to define changes effectively in study area. Hence it is not preferred in plane areas devoid of any tall structures.

CVA method in the study area gave most accurate results (Table 5). An accuracy value of 84.29% with kappa of 0.69 was obtained which revealed that CVA is the most apt technique for detecting changes of agricultural villages of south India. It can be well used in studying changes due to an irrigation project, since it gives direct results on moisture reduction, bare soil expansion, water or high moisture land and chlorophyll increase. Apart from other tests, they also indicate the direction of change.

Table 4: Change percentages, overall accuracies and kappa coefficients

	Change image	Change area (%)	Overall accuracy (%)	Kappa		Change image	Change area (%)	Overall accuracy (%)	Kappa
Image Differencing	Diff 1	23.74	71.43	0.44	Image ratioing	Rto 1	14.74	44.29	-0.17
	Diff 2	19.46	67.14	0.35		Rto 2	14.99	54.29	0.05
	Diff 3	17.85	70.00	0.49		Rto 3	13.5	57.14	0.13
	Diff 4	27.79	77.14	0.51		Rto 4	34.89	71.43	0.41
	Diff 5	7.68	72.86	0.47		Rto 5	12.31	58.57	0.16
	Diff 6a	13.38	67.14	0.34		Rto 6a	14.19	44.29	-0.09
	Diff 6b	10.09	67.14	0.35		Rto 6b	14.3	57.14	0.14
	Diff 7	8.24	71.43	0.45		Rto 7	14	64.29	0.30
	Diff 8	21.0	64.29	0.31		Rto 8	27.06	55.71	0.14
PCA	Pca 1	26.72	72.86	0.46					
	Pca 2	24.03	75.71	0.51	CVA	ΔCVA	16.28	84.29	0.69
	Pca 3	24.18	71.43	0.44					
	Pca 4	31.41	67.14	0.34					
	Pca 5	12.91	80.00	0.60					
	Pca 6a	25.44	61.43	0.25	TCT	ΔB	8.13	84.29	0.68
	Pca 6b	29.03	64.29	0.28		ΔG	18.50	74.29	0.46
	Pca 7	16.82	65.71	0.32		ΔW	19.82	80.00	0.60
	Pca 8	26.03	64.29	0.31					

Table 5: Change percentages in CVA

Dimensions/ Level	Moisture reduction (I)	Bare soil expansion (II)	Water or high moisture land (III)	Chlorophyll Increase (IV)
1. No change	3.53	9.19	6.70	65.30
2. Change	0.09	0.49	2.35	12.77

TCT on study area gave change in Brightness, Greenness and Wetness. In accuracy assessment, brightness change excelled with an accuracy of 84.29 % and a good kappa value. Brightness change is an indication of soil reflectance. So it can be used in detecting phenomena like regeneration and deforestation. Greenness change and Wetness change also gave good accuracy and kappa value. So in general TCT method is well suited for the study area, standing next to CVA analysis in the list. PCA method also gives change percentages in each band. The accuracy assessment of Band 5 (shortwave infrared) and Band 2 (green) gave good results, thus can be used for detecting change in type of vegetation and water quality.

5. Conclusion

A variety of change detection techniques always produces different accuracies according to the nature of the study area. The objective of this study was to examine the effectiveness of five CD algorithms on a typical south Indian agricultural village. It was concluded that among the five methods tested CVA is the most apt technique for the study area. Conjointly bountiful results were obtained; marking out best methods that can be used in tracking specific changes in biomass content, water quality, etc.

The findings of this study can be summarized as follows:

1. Image differencing was simple, straightforward technique and interpreting the results was easy. It can be applied to the study area to detect changes on vegetation health, biomass content etc. of the study area. But only magnitudes of these changes can be obtained. Almost all the band differences gave results with good accuracy.
2. Ratioing was unable to define changes effectively in environments such as the study area. It provided limited change information and yielded the lowest accuracy compared to other techniques. Thus it is not preferred in plane areas devoid of any tall structures.
3. PCA technique can be used for detecting change in type of vegetation and water quality owing to band 5 and band 2 change accuracy.
4. CVA method was the most accurate one for capturing and identifying changes in the area. It can be well used in studying changes due to an irrigation project, since it gives direct results on moisture reduction, bare soil expansion, water or high moisture land and chlorophyll increase. Apart from other tests, they also indicate the direction of change.

In general we can say that different change detection algorithms in Matlab are simple and user friendly, but have to be compared to find the best method for specific application and regions. The GUI package hence proves to be an effective study tool which helps in quick analysis of satellite images. The present study reveals that CVA, TCT, simple differencing of band 4 and PCA of band 5 are recommended methods of change detection in tropical agricultural region of India.

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