Differential Geometric Approach to Change Detection Using Remotely Sensed Images

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Abstract— **Change Detection using multi-temporal satellite images of same area is an established as well as actively pursued research problem. Most of the change detection techniques use algebraic or transform methods to do a pixel by pixel comparison of change detection. These techniques heavily depend upon the correct choice of threshold value to segregate the real changed pixels from the apparent changed ones. Also all these techniques can only compute the two dimensional change of the terrain surface from remotely sensed data. In this paper we propose a differential geometry approach to detect changes from remotely sensed images, which can detect the change using the geometric property of the pixels with respect to its surroundings. It can compute and filter the changed pixels having high curvature from that of flat (2D) changed pixels.**

Keywords-Change Detection, Difference of Gaussian, Hessian, Differential Geometry, Spatio-Temporal Change Detection

I. INTRODUCTION

Timely and accurate change detection of Earth's surface features is extremely important for understanding the effect of manmade and natural phenomena on the surface of Earth. This helps in taking appropriate spatio-temporal decisions for preserving the Earth resources and utilizing them effectively.

Change detection has been researched extensively in past one decade and has a sizable literature on the techniques, analysis and applications in the form of survey of research literatures [1], [2], [3]. The primary sources of input data for change detection are remote sensing data obtained from different satellites or photographs taken from aerial vehicles at different instants of time. As the number and frequency of satellites observing the earth surface has increased, there is a growing demand for timely and accurate detection of change information regarding earth surface. With the availability of high spectral and spatial resolution image data, the focus of change detection techniques has changed from pixel-wise change to object change [7], [9].

Due to the importance of monitoring change of Earth's surface features, the change detection problem continues to be an active topic of research [4], [5]. Surveys of change detection research methods [2], have categorized all the change detection techniques into three broad categories: (1) algebraic method (2) Transform based methods and (3) post-classification comparison. Most of these change detection techniques make use of the spatial and spectral property of the pixels in the image to compare and compute change in spectral characteristic of the pixels. Hence they suffer from the following short comings.

(a) All these methods need appropriate selection of threshold value to segregate the real change information from apparent change in the surface.

(b) These methods only can predict the two dimensional (2D) surface change from the remotely sensed images leaving the interpreter to figure out any change in structure or three dimensional change.

None of the published algorithms use the contextual information and geometric information associated with the pixels to detect change [6], [7]. In this paper we propose a technique to classify the pixels obtained from change detection mask into planar (2D) or curved (3D) change category depending upon its curvature with respect to its surrounding pixels. The proposed technique uses differential geometry to compute the curvature of pixels from the differential gray scale profile obtained from multi dated satellite images. It makes use of the mathematical properties of Gaussian and Hessian functions to compute the Gaussian curvature of the changed pixels in the image. Further this classification is formulated in the scale space using the Difference of Gaussian [DoG] with variable spatial width of the Gaussian function. The technique does not depend on the selection of threshold value to differentiate between changed pixels from the no change pixels. Further it makes use of the comparison of the eigenvalues computed from the Hessian applied over the

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difference intensity profile to compute the Gaussian curvature and filters the curved change pixels from the rest of changed pixels.

In the next section we discuss the differential geometry and its functions to simulate scale space of images. In section three we illustrate the working of the proposed technique. The proposed technique has been applied to a set of multi-dated satellite images encompassing different spatial distribution and sensors. The results obtained are analyzed in the last section.

II. DIFFERENTIAL GEOMETRY AND ITS FUNCTIONS

Concepts of Differential Geometry and Curvature play an important role in analyzing and understanding the topology of the objects from the optical profile of the images. In fact the intensity profile of the image is the reflectance optical profile of the surface of the terrain [8] which is captured as a grid of pixels of the image. In this section the twin concepts of curvature and differential geometry are discussed from the fundamentals with their definition, physical significance and applications with relevance to extraction and understanding the shape from images. Differential geometry [8] is a mathematical tool employed to compute and analyze the local difference of the terrain profile from the image. The remotely sensed images record the profile of the intensity reflected by the terrain surface as the image. The concepts like Laplacian, Hessian and Hermitian are the differential measures for computing the geometric deviation or profiles of the objects with respect to its surroundings. Some of the properties that are computed include curvature, principal curvature, Gaussian curvature, mean curvature etc. from the Laplacian and Hessian operators. This section gives the definition of curvature and its variants with their physical significance through the computation using differential geometry.

Before that the important questions like what differential geometry is about, and how it is applied to compute curvature and some applications are addressed. Differential Geometry is the method of computing geometric quantities using differential calculus. It can be connoted as a process of shape description through derivatives. These concepts are made use of in our technique to detect the highly curved changes from the differential intensity profile of the satellite images.

The gradient of an image I(x,y), can be computed using the first order differential known as the Laplacian as given in equation (1).

$$\nabla I(x,y) = \begin{pmatrix} (\partial I(x,y))/\partial x \\ \partial I(x,y))/\partial y \end{pmatrix} - - - - - - - - - - - - - (1)$$

The simplest form of the curvature which usually is used in calculus is the extrinsic curvature. The curvature of the intensity profile of the image which can be expressed as the signed Gaussian curvature, ‘k’ defined by Equation (2)

$$K = \frac{\frac{d^2 I(x,y)}{dxy}}{\left(1+\left(\frac{dI}{dx}\right)^2\right)^{3/2}} - - - - - - - - - - - - - - - - (2)$$

When the surface is given in the form of a matrix which usually is the matrix of pixels representing the optical profile of the surface, the curvature is computed using the differential equations. Also there are a number of different forms of curvature which has closer and significant physical meaning derived from the above principal curvature such as Gaussian curvature, mean curvature etc. Often for practical purpose the dy/dx << 1 and hence the denominator of the equation (2) equals to 1 leading to the curvature as derived in equation (3)

$$K = \frac{\partial^2 I(x,y)}{\partial xy} - (3)$$

The second-order derivative of a plane or second-order geometric quantity that can be derived gives the rate of change of the gradient in the surface which is often connoted as the curvature. This is computed through a matrix of second order derivatives of the pixel values with respect to its neighbor pixels and is known as the ‘Hessian’. The Hessian is computed using the equation (4).

$$H(x,y) = \begin{pmatrix} \frac{\partial^2 I}{\partial x^2} & \frac{\partial^2 I}{\partial x \partial y} \\ \frac{\partial^2 I}{\partial y \partial x} & \frac{\partial^2 I}{\partial y^2} \end{pmatrix} - - - - - - - - - - - - - - - (4)$$

Hessian being a real and symmetric matrix has following interesting properties. Its determinant is equal to the product of its eigenvalues and is invariant to the selection of the spatial coordinate (x, y). The trace of Hessian matrix Tr(H) (i.e. the sum of the diagonal elements) is also invariant to selection of x and y. A proper selection of x and y can produce a diagonal matrix, where the diagonal elements are the eigenvalues and the column vectors are the eigenvectors. The eigenvalues and eigenvectors of Hessian matrix have great geometric significance which is being exploited in the technique given in next section. It is used to study the geometrical topology of the surface to classify the changed pixels into 2D change or 3D type depending on the curvature. The geometric meaning is:

(a)The first eigenvector (The one whose corresponding eigen-value has the largest absolute value) is the direction of greatest curvature)

(b)The second eigenvector (the one whose corresponding eigen-value has the smallest absolute value) is the direction of least curvature.

(c)The amount of curvature in the surface is proportional to the magnitude of the eigen-values.

The eigen-values of the H are called the principal direction of pure curvature and they are always orthogonal. The eigen-values of H are also called the principal curvature and are invariant under rotation. They are denoted as λ_1 and λ_2 and are always real valued. A study of surface property of medical images using eigen-values was reported in [11].

Another differential geometry concept which we use in our technique is Difference of Gaussian (DoG), The Gaussian and Difference of Gaussian functions are given by equations (5) and (6) respectively.

$$G(x,y,\sigma) \quad * I(x,y) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\left[-1\frac{x^2+y^2}{2\sigma^2}\right]} ------(5)$$

Where, σ denotes the width of the Gaussian function with which the input image is convolved. The Gaussian convolved image is a smoothed image, with the degree of smoothing controlled by σ.

$$\mathrm{D}(\mathrm{x},\mathrm{y},\sigma) = \big(G(x,y,k\sigma) - G(x,y,\sigma)\big) * I(x,y) ----(6)$$

The Difference of Gaussian (DoG) of an image is computed using equation (6) where the intensity profile of the image is convolved with Gaussian kernel with two nearby scales 'σ separated by a constant multiplicative factor 'k'. The Difference of Gaussian (DoG), simulates the scale space visualization of the intensity profile of the image.

III. TECHNIQUE FOR CHANGE DETECTION USING DIFFERENTIAL GEOMETRY

Input to the change detection technique is a pair of satellite images I_D and $I_{(D+k)}$ of the same area obtained at different date say date 'D' and 'D+k', respectively. Often the pair of image will not be in common frame of reference for direct comparison of the pixel arrays for change detection, because of the geometric error. Hence there is a need to register the pair of images [10]. The geometric error is a non-linear error imparted to the satellite image because of the instability of the sensor mounted in the satellite. This error is a cascaded arbitrary combination of translation, rotation and scaling of the image. Treating I_D as the base image, $I_{(D+k)}$ has to be aligned to the base image. Hence image $I_{(D+k)}$ is treated as the image having arbitrary geometric error which is affine in nature. Therefore the first step of the process is to remove the geometric error in $I_{(D+k)}$ which is modeled in the pair of transformation equations (7) and (8) given below.

$$X_i = S(x_i \cos\theta + y_i \sin\theta) + h ------------(7)$$

$$Y_i = S(-x_i \sin\theta + y_i \cos\theta) + k -----------(8)$$

Where, the co-ordinates (X_i,Y_i) of image $I_{(D+k)}$ are computed after applying the appropriate scale factor 'S', translation (h, k) and rotation 'θ' to the co-ordinates (x_i , y_i) of the base image I_D. The values of scale factor 'S', rotation 'θ' and translation factor (h, k) are computed using the Log-Polar transformation. [13],[14].

After due geometric registration, the images are in a common frame of reference for algebraic comparison pixel wise.

Because of the image are acquired in a interval of 'k' days which can be of the order of 30 days, the atmospheric conditions are not same. Hence there is a relative radiometric error in the images because of the non-similar atmospheric conditions. The radiometric intensity normalization is performed on the images to remove any radiometric error due to intervening atmospheric conditions.

$$I_{D+k}(X_i,Y_i) = \frac{\sigma_1}{\sigma_2}\left(I_{D+k}(X_i,Y_i) - \mu_2\right) + \mu_1 ------(9)$$

Where μ_i, σ_i ; i=1,2 are mean and standard deviation of grey level intensity of images I_D and $I_{(D+k)}$ respectively [3].

After, geometric registration and radiometric intensity normalization, the image pair are in a common frame of reference for comparison. The pixel-wise difference between the image pair is computed, which is stored in the changed mask C(x,y), as the change intensity profile of the images is computed using equation (10)

$$C(x_i,y_i) = I_{D+k}(x_i,y_i) - I_D(x_i,y_i) -------- (10)$$

In the next step the C(x, y) is convolved with Gaussian function as given in equation (5) and successive Gaussian of C(x,y) are computed with different values of with different sigma viz. for 0.5, 0.6, 0.7 and 0.8 respectively [12]. Spatial Window size of the Gaussian Kernel is kept larger so that the inner pixels of the windows will have more contribution to the Gaussian coefficient compared to the border pixels. In this experiment the spatial window size of the Gaussian is kept constant viz. 9x9.

The Difference of Gaussian (DoG) is computed using equation (6) by convolution of Gaussian function on the changed intensity profile C(x, y) of the images and by taking the difference between the successive Gaussian convolved intensity profile.

The DoGs of the C(x, y) is subjected to computation of Hessian through a moving matrix operator. The eigen-values of the 2x2 Hessian windows at each pixel are computed using the equation (11)

$$H(x,y) * D_k = \begin{pmatrix} \dfrac{\partial^2 D_k}{\partial x^2} & \dfrac{\partial^2 D_k}{\partial x \partial y} \\ \dfrac{\partial^2 D_k}{\partial y \partial x} & \dfrac{\partial^2 D_k}{\partial y^2} \end{pmatrix} ----------(11)$$

The eigen-values of the above matrix (λ_1, λ_2) is computed for each pixel in D_k. The eigen-values hold the information on the relative curvature of the pixel. The pixels are classified as curved or flat depending on the relative value of the eigen-values computed from the Hessian as per the rules given in Table-1. The eigen-values of the Hessian on the intensity profile reflect the relative change of energy of the terrain profile, which in turn reflects the rate of change of slope of the intensity profile.

This process is repeated for three sets of DoG at different values of sigma and the pixels filtered are aggregated to reflect the final set of curved changes in the recently acquired images.

TABLE-I

RULES FOR CLASSIFICATION OF PIXEL USING EIGEN VALUES OF HESSIAN MATRIX

SLN	Rules for classification of changed Pixels depending on the relative eigen values obtained from the Hessian Matrix	
	Condition of Eigen Values	Interpretation of the Change Pixels
1	$\lvert\lambda_1\rvert < \lvert\lambda_2\rvert$ and $\lambda_2 < 0$	Bright vessel like pixel having high curvature against a dark background
2	$\lvert\lambda_1\rvert < \lvert\lambda_2\rvert$ and $\lambda_2 > 0$	Dark vessel like pixel having high curvature against a bright background
3	$\lvert\lambda_1\rvert = \lvert\lambda_2\rvert$	The pixel is a planar surface change

IV. Results and Discussions

Refer to Fig. 1 depicting a set of results obtained after applying the technique to four different image pairs. The results are arranged in the form of matrix where columns (a) - (e) are interpreted as (a) Base Image obtained at Date 'D' (b) Currently acquired Image at date (D+k) after geometric and radiometric error correction (c) 2D Change profiles obtained using the pixel difference between the image in columns (b) and (a) marked with Minimum Bounding Rectangle (d) Curved change pixels in one of the scale space obtained after applying Difference of Gaussian (e) Pixels classified as Highly curved Changes obtained after application of the Hessian rules laid down in Table-1.

The images in third column depict all the changed clusters which have both flat and curved changed pixels. The changed clusters are depicted using MBR (Maximum Bounding Rectangle). The fourth column in each row depicts the Hessian applied on Difference of Gaussian (DoG) of the intensity profile of the changed pixels. The images in the last column highlights only the changed pixels which are classified as highly curved pixels or 3D changes using the Hessian and Gaussian operations. The movement of the aeroplanes from the aerobridge are detected as curved change in the first row. Similarly the construction of houses has been reflected as curved changes in the second set. The fourth row identifies the newly water filled portion of a lake as a curved change in the final result.

The apparent curved changes can be easily observed in the first row of the result set where the aeroplane in the first image has moved away from the docking area of the aero bridge resulting in a highly curved change in the subsequent satellite image. This has been identified as a changed cluster and has been highlighted as a curved changed cluster in the final outcome.

How the change detection method is applied in the scale space of the change profile which is simulated using Difference of Gaussian is depicted in fig. 1. Pixels corresponding to highly curved objects are consistently filtered in successive scale space using the comparative study of the eigen-values of the Hessian matrix for each pixel locations.

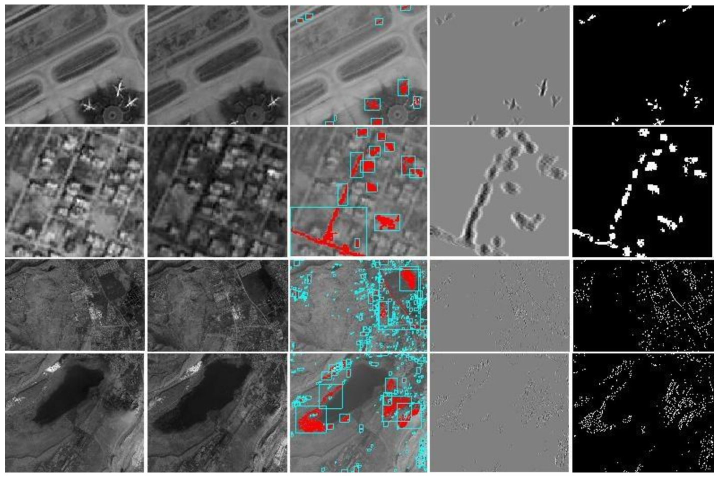

Figure 1. 3D Change after applying the Hessian to DoG of the Image pair.

V. Conclusion

From the result set one can observe that the application of Hessian to the Difference of Gaussian of the changed profile can effectively able to filter the highly curved changes from that of the 2D changes. The above change detection process does not use threshold value to segregate the 2D change pixels from the difference intensity profile. Also it does not use threshold value to filter the curved change pixels (3D) from the 2D change. The filtering of the highly curved change pixels are carried out using the relative magnitude of the eigen-value obtained from the Hessian which involves comparison of values of the eigen values. Hence the process can be implemented as decision rules rather than computing the absolute values. This makes the method more robust because even the computation will sustain for very small magnitude of the eigen-values. Hessian computes the Gaussian curvature of each pixel in the change profile. The method effectively demonstrates the applications of the differential geometric constructs corresponding to the differential equations discussed above for detection of curved changes from 2D satellite images.

References

[1] Singh, A. Review Article: Digital change detection techniques using remotely-sensed data. Int. J. Remote Sensing, Vol. 10, No. 6, pp. 989-1003, June 1989.

[2] Lu D., Mausel P., Brondizio E. and Moran E., Change detection techniques, Int. J. Remote Sensing, 20 June, 2004, Vol. 25, No. 12, pp. 2365-2407, June 2004.

[3] Radke J. Richard, Andra Srinivas, Al-Kofahi Omar, and Roysam Badrinath, Image Change detection algorithms: A systematic survey, IEEE Transactions on Image Processing, Vol. 14, No.3, pp. 294–307, March 2005.

[4] Coppin P., and M. Bauer. Digital change detection in forest ecosystems with remote sensing imagery. Remote Sensing Review., vol. 13, no. 6, pp. 207–234, 1996.

[5] Coppin. P., Jonckheere I., Nackaerts R., Muys B., and Lambin E., Digital change detection methods in ecosystem monitoring: a review, Int. J. Remote Sensing, Vol. 25, no. 9, pp. 1565-1596, May 2004.

[6] Im, J., Jensen, J. R. and Tullis, J. A., Development of a remote sensing change detection system based on neighborhood correlation image

analysis and intelligent knowledge-based systems. In IEEE International Geoscience and Remote Sensing Symposium, Seoul, Korea, 2005.

[7] Im J., Jensen J. R., Tullis J. A., Object-based change detection using correlation image analysis and image segmentation, Int. J. Of Remote sensing, Vol. 29, no. 2, 2008.

[8] Dillen, F. and Koenderink J.J. Image space. in: Pure and applied differential geometry., Woestyne (eds.), Shaker Verlag, Aken, Germany, pp. 149-157, 2008.

[9] Kita, Y., Change detection using joint intensity histogram, In Proceedings of 18th International Conference on Pattern Recognition, pp. 351–356, 2006.

[10] Yu, L., Zhang, D. and Holden, E-J., A fast and fully automatic registration approach based on point features for multi-source remote-sensing images, Computers and Geosciences 34, pp. 838–848, 2008.

[11] Kim, S.H., Lee, J.M., Lee, J-G., Kim, J.H., Lefere, P.a., Han, J.K. and Choi, B.I., Computer-Aided Detection of Colonic Polyps at CT Colonography Using a Hessian Matrix-Based Algorithm: Preliminary Study, American Journal of Roentgeonology, 189, pp. 41-51, 2007.

[12] David G Lowe, "Distinctive Image features from scale-invariant keypoints", International Journal of Computer Vision, vol. 60, pp. 91-110, 2004.

[13] Barbara Zitova, Jan Flusser, "Image Registration methods: a Survey", Image and Vision Computing 21, pp 977-1000, 2003

[14] George Wolberg, Siavash Zokai, "robust Image Registration using Log-Polar Transformation", Proceedings of IEEE International Conference on Image Processing, 2000.

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