IMAGE-BASED CHANGE DETECTION FOR BRIDGE INSPECTION

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ABSTRACT

The changes in defects patterns or in element condition index during visual inspection of bridges are primary concerns for inspectors. This paper presents a new approach for change detection of defects in bridges by identifying changes in texture patterns through spectral analysis of digital images. The commonly used method for change detection is image differentiation. This subtraction method requires images to be of same size, scale, and rotation. However, no two images are same in real practices. Thus, image registration is required to align images and to produce change maps. This process is tedious and it is difficult often to achieve a good registered image. But, the change detection task can be readily modeled in frequency domain for texture patterns discrimination and also for quantifying their properties. This paper proposes a novel approach for change detection by transforming digital images into Fourier spectrum. In new coordinate system, 1-D signature functions can be drawn which facilitates easy comparison of textures in different directions. The proposed methodology provides useful tools for comparison of inspection history graphically and quantitatively. In practice, expensive sensors are used to detect subtle change in defect patterns. The proposed method can be used to detect any subtle change in defect patterns using digital images at much lower cost.

KEYWORDS

Digital Images, Visual Inspection, Change Detection, Spectral Analysis, Bridge Inspection, Image Difference.

INTRODUCTION

In Canada, bridges need to be inspected frequently to ensure that they meet the current operational requirements and fit for use because over 40% of all bridges are older than 50 years (Bisby and Briglio, 2004). In current practices, data collection method for bridge inspection is by making a trip to bridge sites (FEWA 1991; FEWA 1992). Information collected during field visits is fundamental input data source for automated Bridge management Systems (BMSs) software's, such as PONTIS (Gutkowski & Arenella, 199 8). Today's BMSs require data information in a special format which describe the extent and severity of defects for structural members. The major tasks outlined in bridge inspection manuals during routine bridge inspection are two folds (Army Corps, 1993; Navy Bridge Inspection, 2008). The primarily purpose of the routine bridge inspection is to conduct the physical condition of elements in terms of the extent and severity of defects. The secondary purpose is to verify and update the information about structures as reported in last inspection. Traditionally, the routine bridge inspection is carried through visual inspection. Several limitations of visual inspection have been identified in previous research papers. One of the important limitations is that it provides only qualitative information about defects. Nevertheless, visual inspection is laborious, time consuming and influenced by subjective nature of decisions (FEWA 1991). Many attempts have been made to overcome these limitations. In recent years, several automated algorithms which can detect and quantify defects have been developed for concrete structures. However, there is a lack of procedures for automated change detection of defects in bridge structures which can enhance the current bridge inspection practices. This paper proposes a novel image-based change detection algorithm in the frequency domain.

A conventional method of change detection has been applied here by image differentiation method that needs images to be registered before the change detection operation is performed (Guo, Soibelman, an d Garrett, 2009). In the frequency domain, it is not necessary to go through the image registration process and the change detection can be achieved with greater accuracy because this approach considers all the texture behavior into account. The algorithms are tested on a set of real images concrete structures.

BACKGROUND

The change detection has many engineering applications. For examples, people used this technique to monitors earth's surface such as changes due to construction, deforestation, floods, forest fires and other kinds of activities (Mark, 1997). Landis, Nagy, Keane, and Nagy (1999) used high-resolution 3D scanning techniques to measure internal damages and crack growth in a small mortar cylinder by analyzing same specimen at different levels of deformation and loadings. Underwater surveillance video frames from remotely operated underwater vehicles were used to track interesting or mundane objects which helped in sorting interesting objects (Edgington, Dirk, Salamy, Koch, Risi, Sherlock, 2003). In recent years, the concept of change detection through images has been extensively used for medical diagnosis. Bosc, Heitz, Armspach, Namer, Gounot, and Rumbach (2003) used it to find subtle changes between MRI (Magnetic Resonance Imaging) scans for assessing the evolution of a disease over time.

Temporal change information with comparison and analysis among multi-temporal digital images can be achieved through Change Detection (Vongsy, 2007). This approach answers some of the fundamental questions such as, 1) how fast the changes are taking places; and 2) what are the trends of then changes (Shehaby, Semary, Salah, Ibrahim, 2012). However, there are a number of limitations for a successful application of the change detection techniques in the engineering fields. This includes the lack of *apriory* information about the shapes of the changed areas, the absence of a reference background, differences in lighting conditions, atmospheric conditions, sensor calibrations, change in sensing technology, ground moisture, and the alignment of multi-temporal images (image registration) (Townshend, Justice, and Gurney, 1992; Bruzzone and Serpico, 1997; Singn 1989).

The shapes of an object and alignments the images are primarily concerns for automated change detection techniques. There exists a variety of types of defects in concrete bridge inspection. The Norwegian graphic symbols for damages in a bridge as listed in the report of the National Co-operative Highway Research Program (NCHRP SYNTESIS 375, 2007) may be used for defining the defects. These classes are further sub-divided into several sub-classes according to the severity of the defects and their impact on the structural integrity of the bridge elements. It should be noted that in all classes of defects, the unknown size, shapes, and color add a great deal of difficulty in automated defect detection. One particular algorithm may not provide all the information from an image. Therefore, a set of different methods need to be employed in the image analysis process to find an acceptable solution to the automated change detection problem. However, it is also not practical to develop several algorithms for analyzing the images to detect the change in them depending upon the region of interest (Guo, Soibelman, and Garrett, 2009). Additionally, the concepts of the feature matching and object recognition techniques are not suitable for identification and classification of defects due to their unknown geometry. The proposed methodology of change detection based on the spatial and spectral information is expected to overcome these limitations. This approach is successful for the detection of change irrespective of the type of a defect.

METHODOLOGY

The comparison of the existing and the proposed procedures for change detection has been shown in Figure 1. The existing procedure utilizes the image differencing method, while the proposed procedure uses the spectral analysis method to detect changes. Both methods are described briefly here.

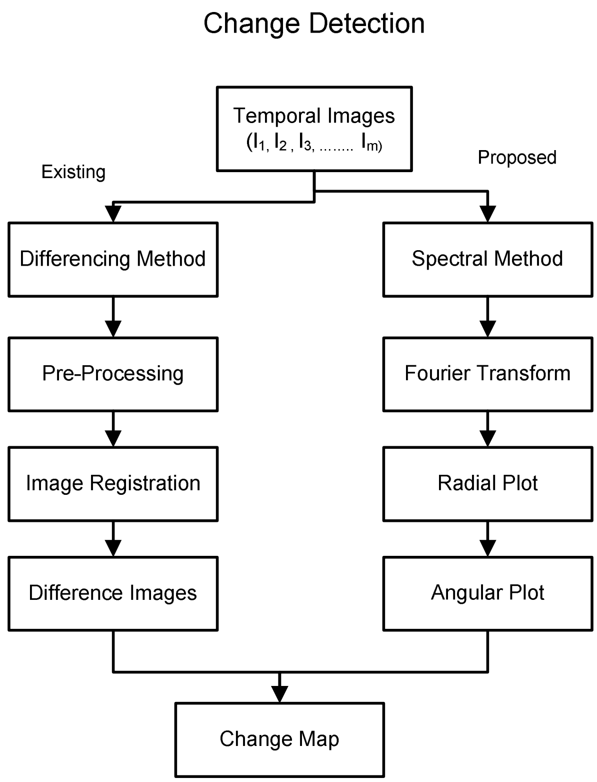

Figure 1 - The Proposed Methodology

Change Detection Through Image Frame Differencing

The following two methods are available for change detection: image differencing and image rationing (Kano, Doi, MacMahon, Hassell, Giger, 1994; Singh, 1989). The first method is easy to understand and is more robust than the image rationing method. However, this approach requires images to be aligned or registered before image differencing process is carried out. The general equation for image differentiation can be written as

$$D(x) = I_2(x) - I_1(x) \qquad (1)$$

where, $I_2(x)$ represents image taken at time T_2 and $I_1(x)$ represents image taken at time T_1. The fundamental change detection algorithm takes the temporal images as input and produces a binary image called a change mask B(x) as defined by the following rule:

$$B(x) = \begin{cases} 1 \text{ if } D(x) > \zeta \\ 0 \quad \text{Otherwise,} \end{cases} \qquad (2)$$

where, ζ is called the threshold and its value is chosen based on the experience or by trial and error method suitable for image segmentation.

The Adopted Image Registration Approach

The image registration is the process of determining an optimal transformation between two images which ensures the alignments of images taken at different times or form different devices. The four components of image registration are: Similarity Criterion, Transformation model, Optimization Method, and Reference and Target images.

Similarity Criterion

The simplest similarity measure is defined by Equation 3.

$$\iint_A (f - g)^{\ 2} \tag{3}$$

where, f = reference image, g = target image, the Equation 3 is called mismatch measure and is nothing more than the sum of square of error double integrated over a given area A. And the normalized cross correlation ($C\,f\,g$) is defined by Equation 4.

$$C\,fg/(\iint_A [g\ 2\ (x + u,\ \ y\ +\ v)\ dx\ dy]\ \tfrac{1}{2}) \tag{4}$$

where, u and v are shift introduced in each pixel of a given image. This allows for linear relationship between the intensities of the two images.

Transformation model

A geometric transformation needs to be applied to the target image. Generally, a rigid model is used when there is no image distortion, and an affine model is used when there is global gross-overall image distortion. The image registration algorithm is applied in MATLAB using "imregister" function which produces the similarity measure and the parameters for the maximization or minimization of similarity process as given by Equations 3-4 (MATLAB –R2012a).

Spectral Approach of Change Detection

Figure 2 illustrates the work flow diagram for the change detection procedure in spectral domain. Spectral descriptors can provide quantitative information of images taken at different times to classify and rank them. For this operation, we need to convert the original images into frequency domain by Fast Fourier Transform (FFT). The obtained spectrum reveals information about the principal direction of textures contained in the images. Also, the location of the fundamental peaks provides information about the fundamental periods associated with the texture of the given images. This method is useful for discriminating between the periodic and non-periodic texture patterns, and for quantifying the differences among the periodic patterns. For convenience, Fourier Spectrum is expressed in polar co-ordinates. This procedure yields a function *S (r, θ)* called the spectrum function, where *r* and *θ* are the spatial variables in polar coordinate system (Gonzalez, Woods, Eddins, 2009).

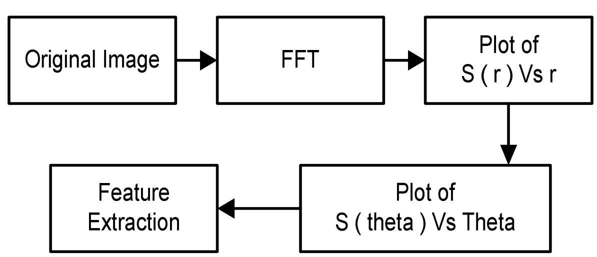

Figure 2 - Change Detection Work Flow Diagram

A global description of the change can be obtained by integrating (summing for discrete variables) these functions as shown in Equations 5 and 6:

$$S(r) = \sum_{\theta=0}^{\pi} S_{\theta}(r) \tag{5}$$

$$S(\theta) = \sum_{r=1}^{R_o} S_{r}(\theta) \tag{6}$$

where, R_0 is the distance from the origin. The typical descriptors include the location of the highest value, the mean and variance of both the amplitude and axial variations, and the distance between the mean and the highest value of the function.

Change Map

<u>Change Map by Image Differentiation</u>

The above discussed two methods of obtaining the change map are studied here through the image registration technique and spectrum analysis, and process is illustrated here in Figures 3 and 4. The Figure 3a shows two images obtained at two different times T1 and T2 and they are displayed together for comparison. In Figure 3b, the images are superimposed to visualize the difference in a certain orientation of the images where the mismatch between the two images is shown in red color. The difference-map of the unregistered images is displayed in Figure 3c. This difference-map cannot be used for change detection because it produces more false negative and false positive objects. Figure 3d shows the registered images and both images are aligned properly. Montage image in Figure 3e shows all distinct objects that are properly aligned, and the red color indicates change objects. For the image analysis purpose, the difference-map as shown in Figure 3f is used for extracting the object's pixel information by applying the suitable threshold values. This algorithm has been tested by using the same images but with different orientation as shown in Figure 4.

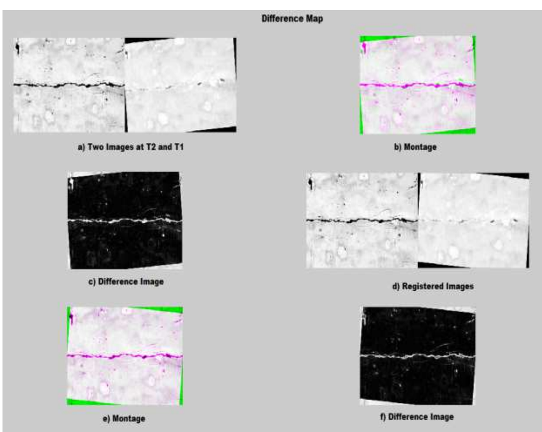

Figure 3: Change Map through Difference Map

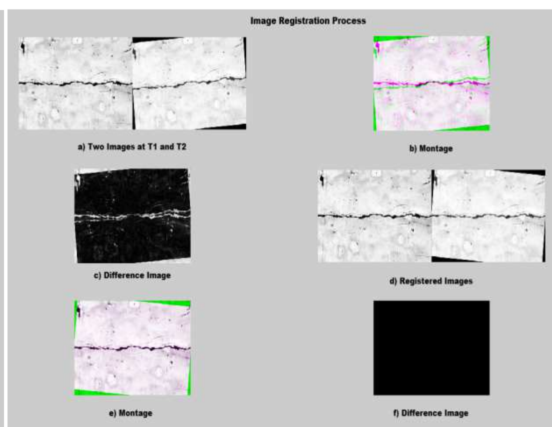

Figure 4: Change Map through Image Registration

The bottom left image in Figure 4 indicates the perfect image registration because there is no red color seen in this image frame. This is confirmed by the difference-image as shown in bottom right of Figure 4 as a null image. The difference-image is then analyzed to find the percentage of change between two images. However, the object-detection techniques (in this case, threshold-based) have a great influence on the quantification of defects and the percentage of deterioration in an image from Time T1 to T2. To make this operation more distinct, the images are analyzed separately and the results are demonstrated below (Figure 5). Figure 5a presents an original image taken at time T1 and the binary image obtained by global image threshold using Otsu's method (with a Gray Threshold level of 0.5) (MATLAB –R2012a). Then, the threshold image is labeled with different color as shown in Figure 5b and the number pixels contained in each object is counted and displayed. Similarly, the image taken at time T2 has threshold of 0.5 and leveled as shown in figure 6a and 6b.

Figure 5a: Image taken at Time T1

Figure 5b: Object labelling and correspon ding area in pixels

However, the images obtained by the above procedure using the threshold of 0.5 do not consider other damages present in the images, such as scaling of concrete surface and surface variability because of climatic effects. Thus, the threshold level in Otsu’s method is increased to 0.8 and the results are displayed in Figures 7 and 8 for the images taken at time T1 and T2, respectively.

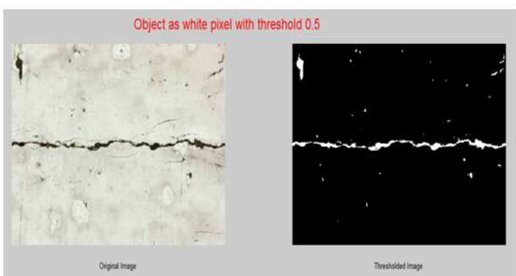

Figure 6a: Image taken at Time T2

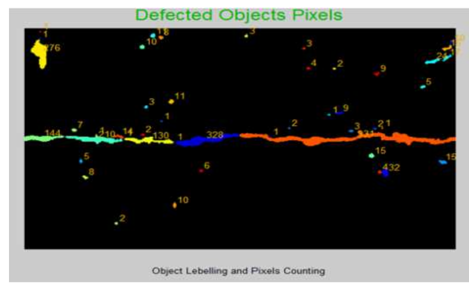

Figure 6b: Object labelling and correspon ding area in pixels

This operation was performed to account for the defects present on concrete surface in the form of textures irregularities. The results are summarized in Table 1.

Figure 7a: Image taken at Time T1

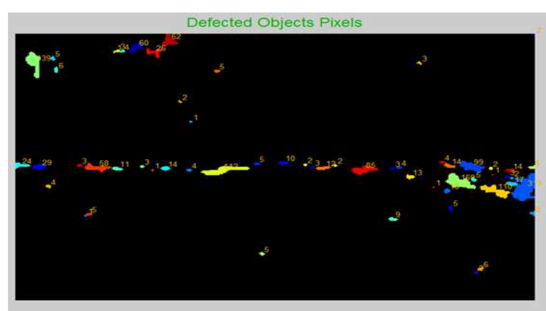

Figure 7b: Object labelling and correspon ding area in pixels

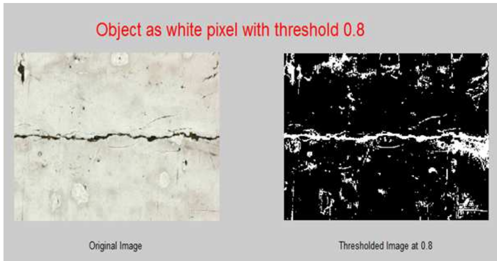

Figure 8a: Image taken at Time T2

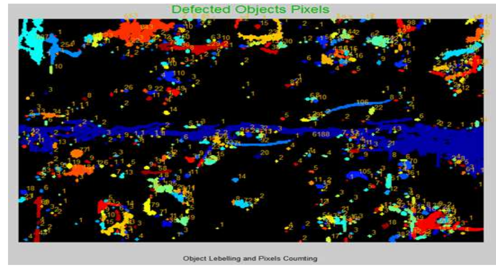

Figure 8b: Object labelling and correspon ding area in pixels

Change Detection by Spectral Analysis

The same images are analyzed in frequency domain as illustrated in the work flow diagram shown in Figure 2. Figure 9 shows the Fast Fourier Transform (FFT) of the image taken at time T2. All the information contained in spatial domain of the image on the left has been retained in the FFT image (right side of Figure 9).

Figure 10 describes the result of the whole process of transforming FFT image to a one-dimensional (1D) representation in the form of energy distribution in the radial direction (middle rows) and angular plot of texture variation in the bottom rows. These plots provide quantitative values of the information contained in both the images and can be used for comparison between them. Here, the mean values of radial and angular plots are of interest to find change detection. The results are summarized in Table 2.

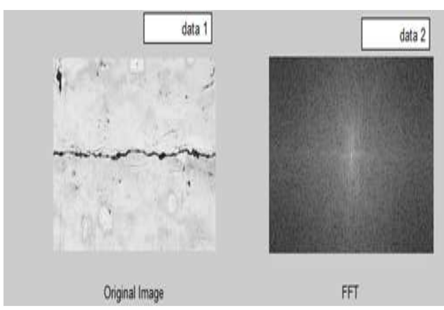

Figure 9: The original Image at T2 and F FT

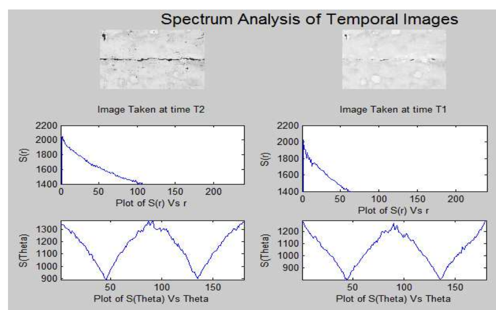

Figure 10: The spectra of the images at T1 and T2

IMPLEMENTATION AND RESULTS

Implementation

The image processing models as described above have been developed in a Window Vista Enterprise 32 bit operating System. The desktop consists of Intel ® Core ™ 2 Duo CPU, E6550 @ 2.33 GHz. The methodology for image registration and spectral analysis were implemented in MATLAB -R2012a.

Table 1 - Change Analysis based on image registration

	Threshold (0.5)	Threshold (0.8)	% defects	% defects	% change
Image Size	298 x 448	298 x 448			
Image at Time T2	2300	14853	1.72	11.13	1.54
Image at Time T1	246	1532	0.18	1.15	9.98

Table 1 shows the result of image registration for the example images at Time T1 and T2, shown earlier. However, the result of the change detection is highly dependent of the chosen threshold for detecting the objects in an image. The number of objects found at a threshold of 0.5 was 46 for image at T1 and 11 for image at T2. Similarly, the number of objects (shown in different color) found at a threshold of 0.8 was 628 for image at T1 and 59 for image at T2. The size of each image is 298 x 448 pixels. The percentage defects in each case were calculated and the percentage change at threshold 0.5 was found to be 1.54%, where as it was 9.98 % at threshold 0.8. This indicates that there is a wide variation in the change metric depending upon how the threshold is chosen for object identification. Table 2 presents the result of the spectral analysis of the same images to detect the changes. The results plotted all the mean values of four plots shown in Figure 10. Both plots revealed that change in both images are higher than 10% which is true because this method considers all possible change in texture in a given image.

DISCUSSION AND FUTURE WORK

The result revealed that the change detection based on image registration greatly depend upon the value of the threshold chosen. At a threshold of 0.5, the change detection map showed only 1.54% change, whereas at a threshold of 0.8, the change was 9.98%. It is interesting to note that at a higher threshold value, more objects pixels were identified as defects which included surface defects such as scaling or change in texture due to dirt on concrete surface. It is not surprising to note that the frequency domain analysis indicated slightly more than 10% change in change-map because it considers all variations contained in the image texture. This method avoids the use of image registration, and the analysis time is much shorter.

Table.2. Change Detection based on Spectral Analysis

	Image at T1	Image at T2	% Change
Mean of Radial Plot	1386*	1537	10.89
Mean of Angular Plot	1055	1167	10.62

**spectral values read from Figure 10.*

This present work overcomes the limitations of the existing methods as indicated by Singh (1989). For example, he stressed the need to explore the possibility of developing a change detection procedure that requires a less precise registration of images or simply bypass the registration process. The reason is that misregistration of images produces a number of false alarms and often a precise registration is very difficult to obtain. Hence, the proposed methodology provides a fast and easy way to detect changes since image registration is not required. A faster method like the proposed one would be useful for a modern Bridge Management System (BMS) to provide a quick comparison of the images taken at different times. The proposed method has been tested for images chosen for particular types of defects. However, it needs to be tested on other types of defects present in reinforced concrete structures. The authors are working to include various types' defects in concrete structures, and potentially apply to steel structures.

CONCLUSION

This paper highlights the importance of change detection and growth of defect patterns during routine bridge inspections. A novel approach for change detection based on spectral analysis has been presented here which shows a better efficiency over the traditional method of change detection based on image difference. The existing technique requires the image registration to be performed first. Hence, the accuracy of that method is solely dependent on the registration techniques. However, image registration process is time consuming and it is difficult to achieve precise registration in many cases. Also, the results presented here show that the change detection map is largely dependent on the value of the threshold chosen for objects segmentation. By changing the threshold from 0.5 to 0.8, the percentage change in defects was found to vary from 1.54% to 9.98%. It is generally difficult to identify which threshold will work well for particular defects in a particular image frame. The proposed approach showed the change detection between the two images, taken at different times, agreed with traditional approach. In fact, the results are slightly higher than previous approach which anyone can expect because the approach considers all the variations present in image-texture which is ignored in the spatial analysis. Thus, the proposed approach provides a method for fast comparison of images and a quick estimate of change in texture patterns in a element since the last inspection. This information provides a great advantage for decision making purpose during routine bridge inspection. In practice, expensive sensors are used for the purpose to finding changes in a structure over time. The proposed technique is cost effective and can be performed as many times as needed to assess the conditions of an infrastructure.

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