# Image-based Retrieval of Concrete Crack Properties

R.S. Adhikari [1]*, O. Moselhi[2], and A. Bagchi[3]

[1] Graduate Student, Concordia University, Montreal, Canada
[2] Professor, Concordia University, Montreal, Canada
[3] Associate Professor, Concordia University, Montreal, Canada
* Corresponding author (r_adhika@encs.concordia.ca)

**Purpose** This paper presents a new method to retrieve concrete crack properties based on image processing techniques. **Method** Detection and quantification of cracks in concrete bridges pose various challenges. Cracks have fewer pixels compared to their background. For effective visualization, the objects need to be captured from near field. But it is not always possible to capture the complete cracked surface in a single frame while taking the image from near field. Hence image stitching is required before pre-processing of images for further analysis. Usually retrieved images have low contrast due to environmental and equipment limitations which add another difficulty in image visualization. State-of-the-art image pre-processing as suggested in the literature may not be suitable for images captured in different environmental conditions. This paper discusses various techniques for image enhancement using point processing, histogram equalization and mask processing. Furthermore, a binary image is required to obtain a skeleton of an object. However, the pre-processing techniques cause discontinuity in crack alignment. Morphological techniques (e.g. dilation) are used in this work through successive iteration to ensure connectivity. Then the object skeleton which is unaffected by expanded boundaries is obtained by using skeleton algorithm to retrieve concrete crack properties such as length, bounding rectangle, and major and minor principal axes lengths. **Results & Discussion** The preliminary results obtained using this methodology is capable of retrieving length, orientation and bounding box of the identified cracks. This method is aimed at assisting in obtaining automated prediction of condition state (CS) rating of cracks in bridges. It can be also used as a tool for post-earthquake damage evaluation purposes.

***Keywords**: concrete bridge crack, image stitching, image skeleton, crack properties*

## INTRODUCTION

Bridge inspection reports are the fundamental input parameters for any Bridge Management System (BMS) to access safety and functionality of bridges. Before carrying out any detailed inspection for repair and maintenance, the preliminary inspections of bridges such as counting the number of cracks, maximum length and width of cracks, existence of scaling and spalling defects, and presence of corrosion are important to be recorded in inspection reports. Often, Bridge inspection and maintenance have been manually conducted by making a trip to the site[1,2].

From the structural point of view, the evaluation of crack properties plays a vital role in bridge inspection and decision making process. However, manual retrieval of crack properties presents many difficulties. For example, cracks usually have very small numbers of pixels as compared to their backgrounds. Due to this, it is difficult to locate these cracks from a far field position. In many cases, the inspection of bridge elements from near field may not be possible due to site inaccessibility. Subsequently, crack visualization could be another problem in accessing crack properties due to insufficient lighting conditions or dirt present on the concrete surfaces. To obviate such problems image processing techniques could be used retrieving image properties automatically. The concept of automation based on image processing is becoming popular for bridge inspection process. Image processing techniques have been successfully utilized to detect cracks on concrete surfaces[3].

In this paper, we collect sample images of cracked surface of concrete bridge decks to apply the proposed methods and highlight their limitations to address the above issues. Close range photographs are necessary to enhance cracks properties, but many photographs are required to cover the entire cracked region. This paper discusses image stitching algorithm as well as various image enhancement algorithms to capture cracked image properties which will assist the automation of bridge inspection based on image processing techniques.

## BACKGROUND

Cracks in concrete structures are very common that we see in our daily life which do not only degrade the appearance of structural members but also reduce carrying capacity of whole structures. As a result, crack widths are limited on various concrete surfaces depending upon types of structures. As specified in Ontario Structure Inspection Manual (OSIM), crack width greater than 1.0 mm is considered as poor condition state and crack width less than 0.3 mm is considered as good condition state[4]. Tian et al., 1986 have also mentioned that crack width as one of the parameters for assessing deterioration of concrete surfaces[12]. For the past several years, many machine vision approaches have been suggested to retrieve crack properties using image processing techniques. For example, Abdel-Qader et al.[5] compared the effectiveness of crack detection techniques such as fast Haar transform (FHT), fast Fourier transform, Sobel, and Canny. It was found that FHT was more reliable than the other three techniques. In 2006, Abdel-Qader et al.[6] proposed a Principal Component Analysis (PCA) for pattern recognition (cracked or not cracked) based on Euclidean distance measures as similarity measures. In addition, Cheng et al.[7] proposed a crack detection method based on threshold operation using mean and standard deviation of gray-level image. But the threshold method does not ensure proper connectivity of the crack alignments. To solve this problem, percolation-based image processing method was suggested by Yamaguchi and Hashimoto[8] to correctly detect cracks. But none of the above works discusses the crack stitching problem when crack images are taken from near field. Zhu et al. 2010[9] proposed an automated method to detect large-scale bridge column composed of multiple of close range images. They used SIFT detector (Lowe 2004)[10] to locate an object and artificial neural networks for material recognition to detect column.

However, image quality is highly dependent upon complex environment and lighting conditions. Due to noise caused by irregular illumination, various shadings and moisture present on concrete surfaces, it is always difficult to distinguish cracks from their backgrounds[11]. They separated crack pixels from their background by manipulation of gray-level correction showing bimodal histogram of crack image. For proper image visualization, Yamaguchi et al.[13], addressed that dynamic range of camera and lighting conditions (uniform or non uniform) are important to have satisfactory results. But they do not discuss how these parameters can be controlled if the acquired image is dark or lighting condition is non-uniform. A method has been proposed here to enhance the global appearance of an image based on the spatial domain operation which can directly works on image pixels.

Automatic crack property feature extraction is application dependent[14]. Practically, it is not feasible to develop a generic algorithm to extract any object properties form any images[15]. There is always human intervention at some point in automation process and the acceptable level of human intervention shall be defined based on accuracy, efficiency, and repeatability[14]. Yamaguchi et al.[8] used a calibration line based on crack scale and brightness of the crack. Miyamoto et al.[16] calculated crack width based on the difference of brightness in cracked and un-cracked areas. Additionally, they reported that no unique crack width is obtained even if the intensity is uniform because it is dependent on many factors such as un-uniformity of brightness, angle of view and orientation of cracks. Zhu et al.[9] calculated crack properties based on skeleton segment information and distance field. They calculated average distance of skeleton points and double of the result represents the average crack width.

## METHODOLOGY

In the 2011 Annual report of the office of the Auditor General of Ontario it is recommended that a risk-based approach be used for the ongoing monitoring of inspection[17]. One of the important aspects of risk-based approach in bridge inspection is to determine and compare crack properties with the allowable limits specified for individual members. Figure 1 shows the proposed methodology to retrieve crack properties in bridges.

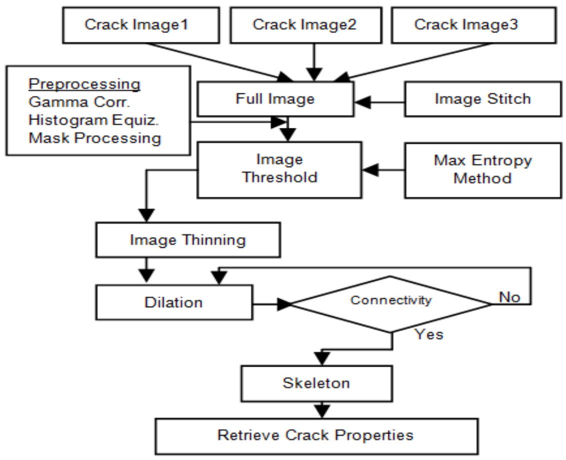



*Fig.1. Research Methodology*

## Image stitching

Cracks have less numbers of pixels as compared to their background. In a single shot of a camera, human eye cannot visualize cracks in bridge elements and hence multiple shots with zooming of camera need to be taken in order to get sufficient information on cracks. These individual crack frames need to be combined first before doing any image operations. This research adopt the image stitching algorithm developed by Brown and Lowe, 2007[18], based on extracting image invariant features and matching them with new images. This method has several advantages over other available methods. This method does not require image initialization or a fixed image ordering. It is based on feature based registration which is invariant to rotation, zooming, and illumination change in the input images[18]. After invariant feature extraction, the algorithm search for matching of images based on overlapping areas. This method is suitable for crack stitching problems for the present work as demonstrated in Figure 2. Two images captured at different parts of a cracked region are shown in Figure 2 (a & b), and the stitched image is shown in Figure 2(c).

(a) (b) (c)

*Fig.2. Example of Image Stitching: a) and b) part images of a crack region, c) stitched image*

**Image pre-processing**

A commercially available SONY-DSC T5 digital camera of 5.1 mega pixels with optical zoom 3x has been used for data collection of bridge crack surface defects. In this work, each photographic frame includes either a natural or artificial target for scale calibration to get pixel values in millimeter. After image acquisition, pre-processing is required for image enhancement. Generally, there are two image enhancement methods that can be applied: spatial domain operation, and frequency domain operation. Spatial domain operation is divided into three parts based on the particular needs. They are point processing, histogram based techniques and mask processing[19]. The proposed method adopts spatial domain operation (directly work on image pixels) as mask processing for crack detection operation and histogram based techniques for visualization enhancement. Both processes are described in details here.

**Histogram Equalization (HEQ):** This method enhances the global appearance of image which helps to visualize small cracks with human eyes. In most cases, fine cracks are invisible due to poor illumination, dirt on concrete surfaces or small dynamic range of cameras. HEQ makes use of a transfer function as defined in Equation 1,

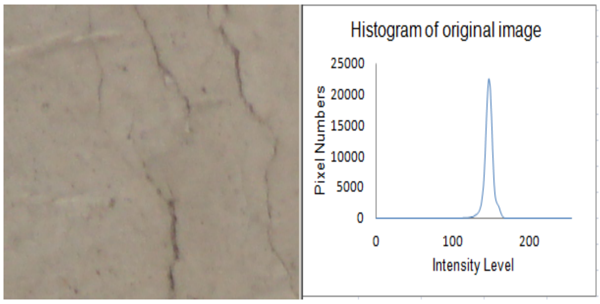
$$S_k = T(r_k) \qquad (1)$$

Where, $S_k$ and $r_k$ are the intensities of the processed and original images, respectively.

The mapping function given by Equation 2 is used to convert the normalized value of histogram to the dynamic range value.

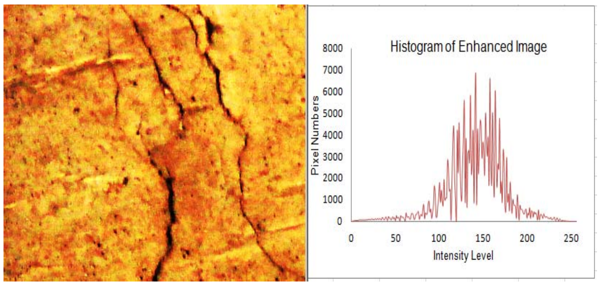
$$S' = \mathrm{Int}\left\{\frac{S - S_{min}}{1 - S_{min}} * [(L-1) + 0.5]\right\} \qquad (2)$$

where, $S'$ is the mapped intensity value, $S_{min}$ is the minimum intensity of the processed image, and $L$ is the maximum intensity level.




(a) (b)

*Fig.3. a) Original Image, b) Plot of Histogram*




(a) (b)

*Fig.4. a) Enhanced Image, b) Plot of Histogram*

The output of the above algorithm has been presented in Figure 3 and 4. Figure 3 shows the original image and the associated histogram, while Figure 4 shows the enhanced image and the resulting histogram. The enhanced image clearly provides a better visualization of cracks than the original image.

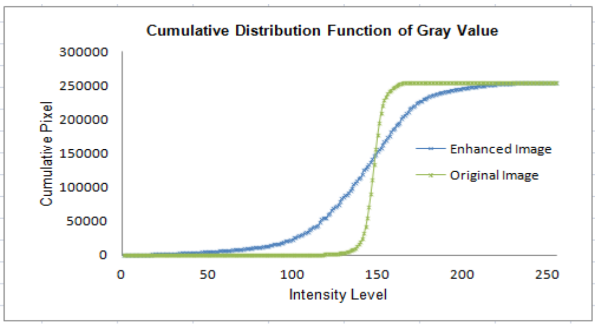



*Fig.5. Plot of Cumulative Distribution Function (CDF)*

The Cumulative Distribution Function (CDF) that can also be used as a transfer function for image enhancement is shown in Figure 5. By designing a special type of transfer function, an image can be enhanced using the histogram specification algorithm[19].

**Mask processing for Crack Detection:**

Mask processing is used for image smoothing purpose. Although mask processing reduces noise, it increases blurring. For this work, a mask size of [7x7] pixels has been used for image smoothing. Also, a non-linear filtering operation (median Filter Operation) which considers an output pixel value equal to the median value of above adopted mask size has been used. The purpose of this process is to obtain candidate cracks as illustrated in Figure 6. This method plots gray intensity level for a selected rectangular area and plots column-wise average intensity of gray value (Fig, 6 – top). Similar operation is performed on the smoothed image (Fig. 6 – middle). The candidate cracks are obtained by subtracting the smoothed image from the original image (Fig. 6 – bottom). The change in intensity profile indicates the presence of cracks[20].

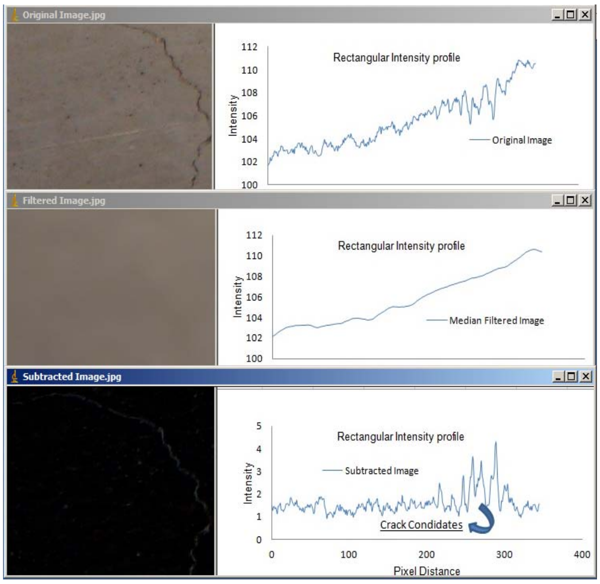


*Fig.6. Procedure of getting Candidate Cracks*

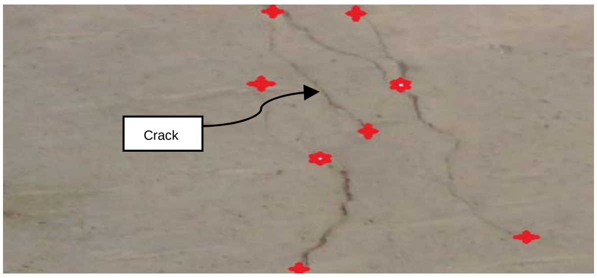


*Fig.7. Crack Properties Definition*

**Retrieval of Crack Properties:**

*Crack Definition:* A crack is defined by the end points, and it may be simple or split (i.e., branched). In Figure 7, cracks are shown by 4-corner stars and splitting points are shown by 5-corner stars. The length of a crack is either distance between end points or splitting points or between an end point and a splitting point[13]. Crack widths are calculated in mm using reference of some natural targets in picture frames.

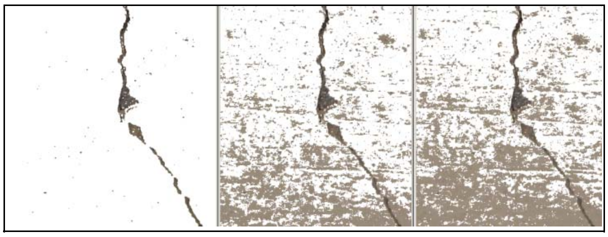

a) b) c)

*Fig.8. Threshold Operations on a pre-processed image: (a) Maximum Entropy; (b) Otsu; and (c) Mean*

*Threshold Operation:* The threshold operation is performed on the pre-processed images using the following three methods: (a) maximum entropy; (b) Otsu; and mean of the intensity in the given image. As shown in Figure 8, the maximum entropy (entropy is a measure of the uncertainty of an event taking place) provides a better contrast to detect a crack. This method maximizes inter-class entropy instead of maximizing inter-class variance.

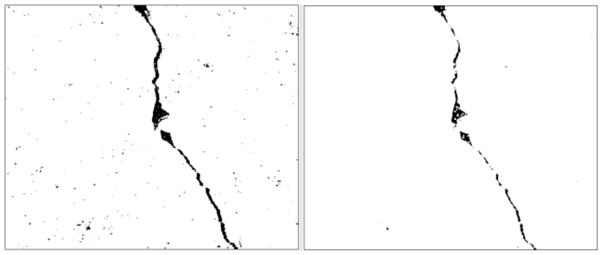

a) b)

*Fig.9. (a) Threshold Image; (b) Eroded Image*

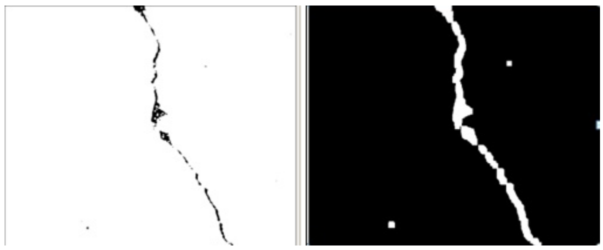

a) b)

*Fig.10. Dilation: (a) eroded image; (b) dilated image*

*Erode and Dilate:* Dilation replaces each pixel in an image with the maximum intensity value in the 3x3 neighborhoods. This operation is performed iteratively until cracks are fully connected. But, before doing this operation, the noise present in an image needs to be eliminated by eroding operation. Figure 9 compares threshold image with eroded image. During eroding operation, many of the pixels in the image are lost which may affect the continuity of the pixel map of a crack. The continuity is re-built by the dilation operation as shown in Figure 10.

*Skeletonise and Distance Map:* A skeletonised crack in a image, represents a single pixel line. The binary image thinning technique is used for constructing the skeleton of an object (e.g., crack). Euclidian distance transform is used to prepare the distance map which is superimposed image the skeleton to extract width and length of crack properties[21]. Distance map and skeleton of a given crack are shown in Figures 11 and 12, respectively.

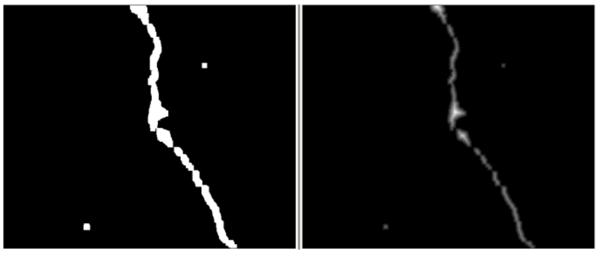


*Fig.11. Dilatation and Distance Map*

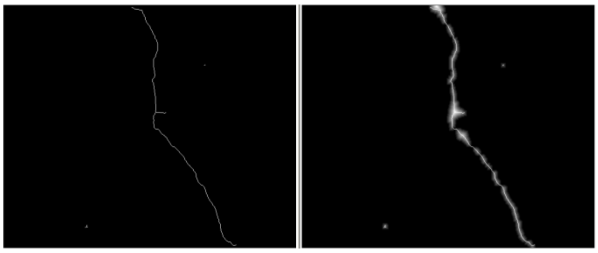


*Fig.12. Skeleton and Superimposed image*

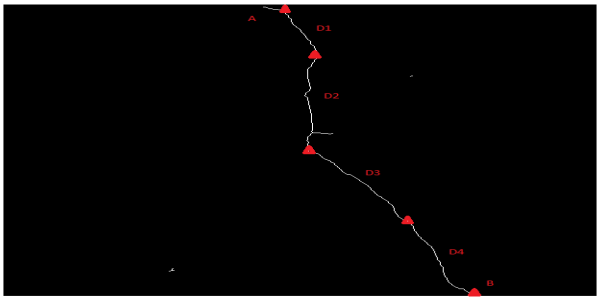



*Fig.13. Crack length divided in segments*

*Table 1*

Crack scaling: 0.5 mm/Pixel

| ID | Length in mm | Width in mm | Average Width in mm |
|---|---|---|---|
| A | 0.00 | 3.25 | |
| | 12.00 | 2.95 | |
| D1 | 23.70 | 3.33 | 3.17 |
| | 45.00 | 2.13 | |
| D2 | 67.05 | 3.67 | 3.04 |
| | 88.00 | 2.48 | |
| D3 | 108.91 | 1.90 | 2.68 |
| | 125.00 | 2.78 | |
| D4 | 141.46 | 1.79 | 2.16 |
| B | | | |

**Implementation and Results**

ImageJ[22] is commercially available image analysis software, which has been used here for image processing of the pictures of cracks in bridge elements. A typical crack-skeleton as shown Figure 13 has been subdivided into 5 segments to extract its length and width based on crack definition. The width is calculated at the ends and the center of each segment. The results are recorded in Table 1. The crack profile such as width vs. length of the crack has been plotted as shown in Figure 14. From such figures constructed for a crack at different time intervals can provide useful information about the growth (in length and width) of the crack.

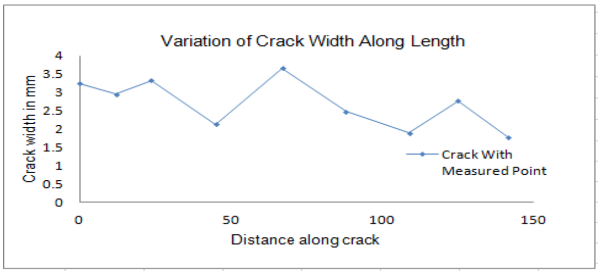



*Fig.14. Crack Profile along Length of Crack*

**Discussion**

A number of methods available for retrieval of the properties of cracks on concrete surfaces has been utilized to develop a systematic procedure for processing of images of damaged areas of concrete surfaces in bridge elements. The proposed scheme is suitable for automatic retrieval of crack properties. But in practical terms, there are a numbers of challenges that need to be considered before applying these algorithms. For example, in old concrete surfaces, cracks edges are often widened because of scaling of plaster or cement mortar. Also, many flacks are often seen along the length of cracks. Due to these defects, predicted crack width would be more than actual crack width.

Inspection report is an integral part in any Bridge Management System (BMS). But manual inspection is time consuming and costly. Tracking concrete surface properties using image processing techniques are fast and less costly. So, this information can be used as primary level of bridge inspection which can provide basis for detailed investigation if any abnormalities exist. The proposed method overcomes some of the limitation pointed out by Zhu et al.[21]. For example, their test results showed that irrespective of how accurate detection techniques are, there are some cracks visible to human eyes, but not visible in images. To some extent, this limitation has been overcome by the proposed method. Moreover, many of the past crack detection methods fail to detect fine cracks. Fine cracks are lost during threshold operation. This problem can also be solved by image stitching techniques as demonstrated in this work. However, a number of challenges exist for inspection of concrete surfaces for effective BMS except those pointed out earlier. Condition rating of concrete slabs is required for ranking of bridges in database to select proper candidate for further maintenance and rehabilitation. Additionally, the existing crack pattern may not be of much important for inspection engineers, but how the crack pattern is changing with time will be valuable information for safety of structures.

## CONCLUSION

Traditionally visual inspection, which is the primary method in use, is slow and expensive. In the present work, image processing techniques are used to extract concrete crack properties. While there are a number of methods available for the crack detection and representation, they are suitable in some controlled situations or in particular images. The present research focuses on visualization of images and detection of thin cracks which are often lost during pre-processing. Cracks have less number of pixels as compared to their background. Histogram threshold is not suitable in such cases because in many cases, crack objects are not visible in histogram plot. For effective visualization of objects, the images need to be captured from a near field. But it is not always possible to capture complete cracked surface in single frame while taking image from a near field. Hence image-stitching is required before pre-processing of images for further analysis. Usually retrieved images have low contract due to environmental and equipment limitation which adds another level of difficulty in image visualization. Existing techniques for image pre-processing may not be suitable in different environmental conditions. A combination of various techniques for image enhancement such as, point processing, histogram equalization and mask processing is necessary to pre-process the images appropriately. Furthermore, a binary image thinning is required to obtain a skeleton of an object. However, pre-processing techniques cause discontinuity in crack alignment. A morphological technique such as, dilation is used to ensure connectivity through successive iteration. From an object skeleton obtained using the skeleton algorithm, the crack properties such as length and width is determined. The proposed method overcomes limitations such as detection of thin cracks which may not persist after pre-processing of an image. The extracted width can be used for condition rating of concrete members and the extracted crack pattern is important for comparing the change in crack patterns over time.

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