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Detection of Cracks Using Different Techniques: A Survey

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Abstract - This paper discusses about available techniques in automated full field mapping of civil structures involving image processing to facilitate real time structural health monitoring. The proposed system incorporates image processing and data acquisition methodologies for crack detection and assessment of surface degradation. The obtained results show that the deployment of image processing in an effective way is a key step towards the inspection of extensive infrastructures.

Keywords – *Crack Detection, Surface Degradation, Image Processing, Morphological Operations.*

1. Introduction

Visual inspection along with image processing is becoming an important arena in civil and construction engineering. The state of the structure has to remain the same as per the design for the entire life span, though this can be altered by normal aging ,by the action of the environment and by accidental events .Inspecting such structures in the early stages of their degradation is critical to their maintenance as their damage may result in further degradation. The degradation of concrete occurs mainly by earthquakes, frost damage, salt erosion, rain water, and dry shrinkage. Cracks on the concrete surface are one of the earliest indications of degradation.

Crack detection is necessary for the inspection, diagnosis, and maintenance of concrete structures, but conventional approaches could not achieve much precise detection since the image of the concrete surface contains various types of noise due to different causes such as concrete blebs, stain, insufficient contrast, and shading. The predominant method for crack inspection is to prepare a detailed sketch of the cracks and to simultaneously measure the condition of the concrete manually. However, the time consuming manual approaches need expertise and have computational complexity. Conventional methods that do not use the crack characteristics cannot able to distinguish cracks from noisy images and results in misidentification.

Nowadays much research effort has been put in the area of developing new techniques of crack detection. To deal with damage assessment in various infrastructures structural health monitoring (SHM) is introduced, which includes the observation of a structure over time using periodically spaced measurements. Then extraction of damage sensitive features from these measurements followed by statistical analysis is performed to determine the present state of system. Such kind of automated frameworks with numerous innovative algorithms tries to get over manual errors and result in better detection of cracks. Hence automatic image based crack detection is proposed, deploying different image processing techniques in an effective way. The noteworthy benefit is, digitization of whole monitoring activity facilitates easy storage, sharing and better accessibility to end users.

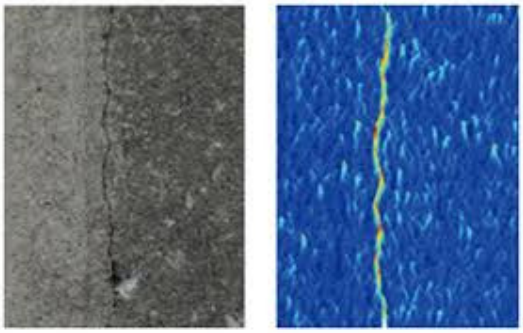

Figure 1. Crack detection of an image

2. Techniques

2.1 Thresholding

The thresholding segmentation is to select an optimal gray-level threshold value for separating objects of interest in an image from the background based on their gray-level distribution. Threshold techniques can be categorized into two classes: - global threshold and local (adaptive) threshold. In the global threshold, a single threshold value is used in the whole image. In the local

threshold, a threshold value is assigned to each pixel to determine whether it belongs to the foreground or the background pixel using local information around the pixel.

Miss Hetal J. Vala et.al. [1] describe a study on various Otsu algorithms used in image thresholding. Otsu method, a global thresholding selection method used of its simplicity and effectiveness. Otsu is an automatic threshold selection region based segmentation method. Otsu's method uses an exhaustive search to evaluate the criterion for maximizing the between class variance. Otsu's method can be considered as better threshold selection method for general real world images with regard to uniformity and shape measures.

Salem Saleh Al-amr et.al [2] describe the different threshold segmentation techniques in their paper. One important threshold technique is Histogram Dependent Technique (HDT). The histogram based techniques is dependent on the success of estimating the threshold value that separates the two homogenous regions of the object and background of an image. This requires that, there exists a threshold value that separate these regions with in the same image. The (HDT) is suitable for image with large homogenous region and it will separate regions where all area of the objects and background are homogenous excluding, the area between the objects and background. This technique can be expressed as:

$$D(T)=C_1(T)\sigma_1^2(T)+C_2(T)\,\sigma_2^2(T) \quad (1)$$

Where D (T) is the within-group variance, C_1 (T) is the probability for group with values less than T, C_2 (T) is the probability for group with values greater than T, σ_1 (T) is the variance of group of pixels with values less than or equal T, σ_2 (T) is the variance of group of pixels with values greater than T.

T.Romen Singh et al [3] present a locally adaptive thresholding technique that removes background by using local mean and mean deviation. This paper develops the binarization of grayscale documents using local adaptive thresholding technique. Local binarization methods compute thresholds individually for each pixel using information from the local neighborhood of the pixel. This paper presents a fast approach to compute local thresholds without compromising the performance of local thresholding techniques using the technique of integral sum image as prior process for finding local mean of the neighboring pixels in a window irrespective of window size. The pixel p(x,y) after applying threshold is :

$$p(x,y)=\begin{cases}1, & if I(x,y)\le Th(x,y)\\ 0, & otherwise\end{cases} \quad (2)$$

$$Th(x,y)=m(x,y)\left[1+k\left(\frac{\partial(x,y)}{1-\partial(x,y)}-1\right)\right] \quad (3)$$

Where m(x,y) is the local mean, $\partial(x,y)$ is the mean deviation, Th(x,y) is the threshold value, k is a bias value varies from [0,1].

This paper states that calculations of mean are independent of window size which can speed up the process as compared to other local thresholding techniques. In terms of both quality and speed, the proposed technique found to be better than other contemporary methods.

2.2 Filtering

Image processing operations implemented with filtering include smoothing, sharpening, and edge enhancement. Filtering is a neighborhood operation, where any given pixel value in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel. Ruchika Chandel et.al [4] discussed about various image filtering techniques such as spatial filtering, temporal filtering. Image filtering algorithms such as linear and nonlinear filters are also discussed. They have compared and evaluated the performance of different image smoothing algorithms.

Vijay Kr. Srivastava et.al [5] design the high pass Butterworth IIR filters using MATLAB considering different parameters such as cutoff frequencies, order and represents the variation of these parameters on noise. This paper investigates the unique property of Butterworth High Pass filter in terms of magnitude responses in the pass band, stop band, and transition band regions to remove noise from the signals.

Jan Mark Geusebroek et.al [6] describe the anisotropic Gaussian filtering method having high spatial and angular accuracy for the fast calculation of edge and ridge maps. The proposed method enables the practical applicability of orientation scale-space analysis. They derived the decomposition of the anisotropic Gaussian in a 1-D Gauss filter in the x-direction followed by a 1-D filter in a non orthogonal direction – φ, which is efficient from a computing perspective. They proposed an implementation scheme for normal convolution and for recursive filtering. Aziz Makandar et.al [7] show the implementation of low pass and high pass filtering techniques to be used in Fourier and Wavelet Transform. They found that high pass filter preserves the edge details and low pass filter preserves the details as well as de-noises the image. In both cases, Gaussian filter is more applicable for transformation which has minimum RMSE and maximum PSNR values.

2.3 Morphological Operations

Morphological operations process images based on shapes, which apply a structuring element to an input image thereby creating an output image of the same size.

In morphological operation, the value of each pixel in the output image is based on a comparison of the corresponding pixel in the input image with its neighbors. The two important such operations are dilation which adds pixels to the boundaries of objects in an image and erosion that removes pixels on object boundaries. M. Kowalczyk et.al [8] found that morphology has an ability to make close range photogrammetric technology faster and can simplify a human work. This paper presents conception of effectively working groups of morphology functions in particular image cases. They found right configuration of morphology tools for obtaining exact results in many photos, especially many photos of same object. They have proposed that the application of morphological gradient gives results that are comparable to the results of widely used operations, like Prewit and Sobel operations.

A. M. Raid et.al [9] presented image restoration based on morphological operations. Morphological image processing extracts image components for representation and description of region shapes and can be used for filtering, pruning and thinning. In this paper morphological operations such as dilation, erosion, opening and closing are implemented in matlab program with parameters of SE are changed much simpler with user interface. K. Sreedhar et.al [10] proposes a frame work which is used to detect the background in images characterized by poor contrast. Image enhancement has been carried out by the two methods based on the Weber's law notion. The first method employs information from image background analysis by blocks and the second transformation method utilizes the morphological operations. In this a methodology was introduced to compute an approximation to the background using blocks analysis, was subsequently extended using mathematical morphology operators.

2.4 Classifiers

Classifiers are intended to assign classes with homogenous characteristics that discriminates multiple objects from each other with in an image.ie, it divides the feature space based on a decision rule.

Nameirakpam Dhanachandra et.al [11] proposed K-means clustering algorithm used to segment the interest area from the background. The proposed algorithm uses partial contrast stretching, subtractive clustering, k-means clustering and median filter. Subtractive clustering algorithm is used to generate the centers, based on the potential value of the image and further used by K-means algorithm for segmentation. The potential of data point x_n is defined as

$$P_n = \sum_{i=1}^{n} e^{\frac{-4x_n - x_i^2}{r_a^2}} \quad (4)$$

Where r_a is hyper sphere cluster radius in data space, which is a positive value.

Bruno Cornelis et. al [12] proposed a semi-supervised crack detection method for high-dimensional acquisitions of paintings of different modalities using non-parametric Bayesian classifier. In this paper the proposed classifier is assessed by visually comparing classification results with the Random Forest algorithm. The proposed method has the noteworthy property that it is nonparametric and once the most important predictors are selected, it works faster than random forest classifier. The paper also shows that different modalities are beneficial for accurate crack detection, as they provide more information and can able to combine the information from different modalities.

Le Hoang Thai et.al [13] proposed a new strategy for combining two areas which are Artificial Neural Network (ANN) and Support Vector Machine (SVM) applying for image classification. Firstly, they separate the image into many sub-images based on the features of images, then each of them is classified into the responsive class by an ANN. Finally, SVM has been compiled for ANN classification result. The proposed method is easy to design and deploy for the specific classification problem with high precision.

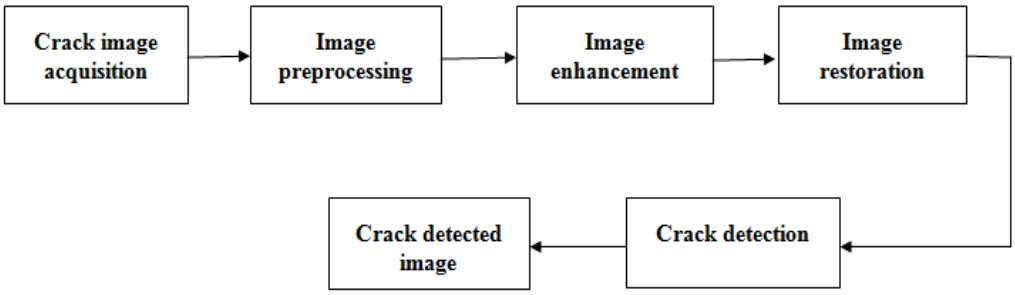

Figure 2. Basic crack detection steps using image processing

3. Literature Survey

Ioannis Giakoumis et. al [14] introduced an integrated methodology for the detection and removal of cracks on digitized paintings. The cracks were detected by thresholding the output of the morphological top-hat transform then, the thin dark brush strokes are removed using either a median radial basis function neural network on hue and saturation data or a semi-automatic procedure based on region growing. The top-hat transform is defined as follows:

$$g(x) = f(x) - f_{nB}(x) \quad (5)$$

Where $f_{nB}(x)$ is the opening of the function f(x), nB is the structuring element.

Lastly, crack interpolation is done using order statistics filters or controlled anisotropic diffusion. This methodology has been applied for the virtual restoration of images and was found very effective in paintings of great cultural and artistic prominence. The problems identified in this paper are detecting cracks located on very dark image areas found to be inefficient and also in the case of cracks that cross the border between regions of different color.

Shruti Garg et. al [15] proposed a method for crack detection in paintings followed by classification method and the results were compared.

Table 1. Results after classification

Techniques	Brush strokes	Crack pixels
Nearest neighborhood	1591	5344
Back propagation	448	6487
K-means algorithm	259	6693
Fuzzy c-means algorithm	5344	1591

K-nearest neighborhood, Back propagation algorithm, K-means clustering, Fuzzy c-means algorithm were applied in this paper for crack classification, intended to separate brush strokes from cracks.

Li Zhe et.al [16] proposed a novel algorithm for crack detection based on improved K-means algorithm. The algorithm initially utilizes histogram algorithm to find the initial clustering center, and then uses the combination of improved K-means algorithm and the region growing algorithm that designs a new distance function and increases a weight related to crack distance region to extract crack. The algorithm can effectively abstract the crack information in non-uniform illumination, and improve the performance. In practical applications cases, the output is not precise.

B.santhi et.al [17] proposed automatic detection of pavement crack using edge detection operation. First, the images are processed by gray scale morphological processing. Then, the final result is obtained by filtering the images by Butterworth filter and then applying the canny edge detection algorithm. The Butterworth filter can be of the form:

$$H(\omega) = 1/[1 + (\omega/\omega_0)^{2n}] \quad (6)$$

Where ω is the frequency of the filter, n is the order of the filter.

In this paper edge based segmentation technique is used for the detection purpose. In order to detect edge precisely, the image is filtered using Gaussian filter. Then strength of the edge is detected by taking gradient estimated in all directions of the image. To intensify the edge detection non maximum suppression is applied further and then Hysteresis is used to eliminate streaking. Even hairline crack can also be detected efficiently by this method with low error rate, the edges are localized and each edge is detected only once. The limitations of this algorithm are the given image has to be pre-processed to obtain a grayscale image with square sized dimensions for further processing.

Priya Ranjan Muduli et.al [18] et.al proposed crack detection, which combines the best features of canny edge detection algorithm and Hyperbolic Tangent filtering technique using an efficient Max-Mean image fusion rule. The fusion of detector responses is performed using Haar Discrete Wavelet Transform (HDWT) and maximum-approximation with mean-detail image fusion algorithm. Haar transform decomposes a discrete signal into two sub signals of half its length. One sub signal is a running average or trend, the other is a running difference or fluctuation. Haar wavelet function ψ(t) can be of:

$$\psi(t) = \begin{cases} 1 & 0 \le t \le 0.5 \\ -1 & 0.5 \le t \le 1 \\ 0 & otherwise \end{cases} \quad (7)$$

The proposed system gives improved edge detection in images with superior edge localization and higher PSNR.

E. Balasubramanian et.al [19] proposed a novel approach combining hat transform and HSV thresholding technique along with grey scale thresholding for crack detection and also for the measurement of surface degradations in civil infrastructures. Most of the crack detection methods rely on detection on gray scale images, though gray scale approaches yield good results, they suffers from misidentification of other structural edges as cracks and results in surplus detection .To overcome these a new strategy combining the hat transform and HSV thresholding technique is proposed in this paper. In HSV thresholding by properly setting the limits in HSV space,

the object or element of interest can be extracted from the scene. Thereafter surface degradation assessment can be done by a simple grey scale thresholding, which is used to classify the unaffected regions among surface degraded portions.

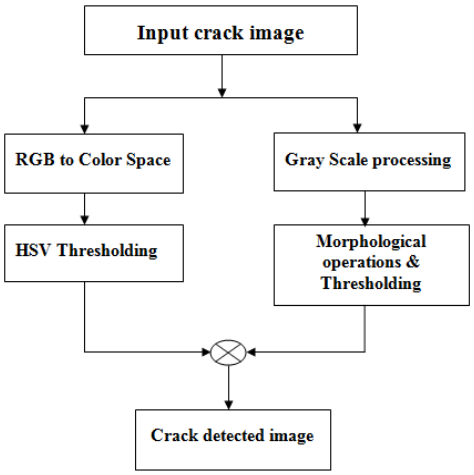

Figure 3. Proposed crack detection architecture

3. Challenges

Many existing methods concerning tracking of crack detection in structures could not achieve precise detection. Hairline cracks existing in the structures cannot be identified with the prevailing techniques. Cracks with poor contrast and non uniform illumination are not easy to identify and may yield erroneous results. Detecting cracks in very dark images are also difficult. Also, problem occurs with identification of cracks that exist in the border between two different colors. Predominant crack detection methods undergo gray scale processing of images, though it seems to be good enough, unaffected areas are also identified as cracks.

4. Conclusion

Different techniques have been emerging in the field of crack detection and assessment of structures. This survey paper overviewed different approaches regarding crack detection. More research is needed though in order to improve the prevailing issues with regard to visual inspection. This paper mentioned techniques such as detection based on edge detection, Morphological top hat transform, Improved K-means algorithm, Image fusion. Detection through gray scale imaging found to be resulted in misidentification of cracks, so a color based model with morphological operation seems good in the investigation.

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