A Novel Technique for Wall Crack Detection Using Image Fusion

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Abstract— **A Non-Destructive Testing (NDT) has been a popular analysis technique used in industrial product evaluation and for troubleshooting in research work without causing damage which can also save both money and time. This paper deals with a novel crack detection technique based on NDT for cracks in walls suppressing the diversity and complexity of wall images. The detection technique begins with wall image acquisition. The acquired image is processed through two crack detectors which follow different edge tracking algorithms such as Hyperbolic Tangent (HBT) filtering and canny edge detection algorithm. The main advantage of the proposed model is that it combines the best features of both Canny's filtering and HBT filtering techniques. It also fulfills the three necessary vital criteria, i.e. accurate edge detection, localization and minimal response, making the crack detection process more robust and reliable. The fusion of detector responses are performed using Haar Discrete Wavelet Transform (HDWT) and maximum-approximation with mean-detail image fusion algorithm to get more prominent detection of crack edges. The proposed system gives improved edge detection in images with superior edge localization and higher PSNR.**

Keywords- Wall Cracks; Non-Destructive Evaluation; Discrete Wavelet Transforms; Hyperbolic Tangent Filter; Image Fusion; Graphical User Interface.

I. INTRODUCTION

Hairline cracks in walls are typically developed within few months or years. In most cases, the common wall cracks pose no structural concerns of foundation failure. The biggest problem they cause is water leakage. As the wall gets wet and dry repeatedly, it expands and shrinks, exerting lateral pressure on the walls creating damages. In a concrete wall, the typical foundation crack will run vertically or at an angle. It is caused by shrinkage of the concrete as it cures. Although human operator based crack detection methods have successfully illustrated that by manually tracking the start and end of a crack, one can use pixel-based algorithms to define the crack characteristics. Many literatures concerning tracking of defects in civil structures are unable to identify the crack edges accurately due to poor contrast, uneven illumination and noisy environment. Complications due to the inherent noise in the scanning process, irregularly shaped cracks, as well as wide range of background patterns are also challenges for error free detection in camouflaged environment. Therefore a new crack detection technique is required which is based on Non Destructive Evaluation (NDE) along with some efficient edge detection algorithms and an efficient image fusion technique to combat contrast, noise sensitivity and uneven illumination. Since more than 25 years, so many systems have been developed which basically deals with detection of linear features on optic imaging [1]. Basically it has been tried to combine a local criterion using evaluating radiometry and a global criterion using wide scale knowledge for edges to be detected. In many cases local criterion are insufficient in detecting very fine crack edges. Some classical gradient-magnitude (GM) methods [2], [3] are usually dependent on edge strength; hence, weaker edges due to texture may not be detected. An alternative method for detecting edges regardless of their magnitude is being proposed [4]. It is based on the computation of the cosine of the projection angles between neighbourhoods and predefined edge filters. So it is otherwise known as an angle-based (AN) method. But this technique is very sensitive to noise and uneven illumination. Local thresholding of image gradients are also sensitive to uneven illumination since they inhibit low luminance regions. The improved method based on phase congruency described the frequency domain image representation [5]. Since an edge exists near points of maximum phase congruency, such methods are invariant towards uneven illumination and low contrast. Due to the use of the log polar Gabor filter, they produce poorer edge localization in those false edges and are detected in the vicinity of sharp transitions. A contrast invariant edge detection method [6] based on the Helmholtz principle describes edges as geometric structures with large deviations from randomness; but, sensitive to the window size and edge localization. The other filter projected by Marr and Hildreth suffers from the problems affined to zero-crossing approach [2]. This approach is basically undeviating in edge localization, provided these are properly separated when the

SNR in the image is high. Again the localization of the real edge dislodges for a bounded width staircase steps. The secondary issue is related to the identification of false edges. Laplacian of Gaussian filter also can't deal with the missing edges. However, merging Laplacian of Gaussian filtering and zero crossing approach is a unmanageable job. Because, an edge does not cope with a zero crossing for very confined number of steps. A robust edge detection algorithm [7] produces superior result than the methods discussed above. This method basically emphasizes on optimizing two of Canny's criteria- accurate edge detection and localization, without explicitly including the third criterion i.e. minimal response. This paper is organized as follows: Section II describes the proposed crack detection technique hierarchy. Section III shows the simulation results and discussion along with the system performance evaluation. Section IV concludes with the highlights of proposed crack detection technique and some safeguards.

I. PROPOSED CRACK DETECTION TECHNIQUE

We have proposed a model for an efficient and reliable 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. Here the detection architecture consists of the some major steps as follows:

(1) Acquisition of concerned wall image.
(2) Crack detection using two efficient algorithms.
(3) Wavelet decomposition and Fusion.

The proposed algorithm is shown in Fig.1

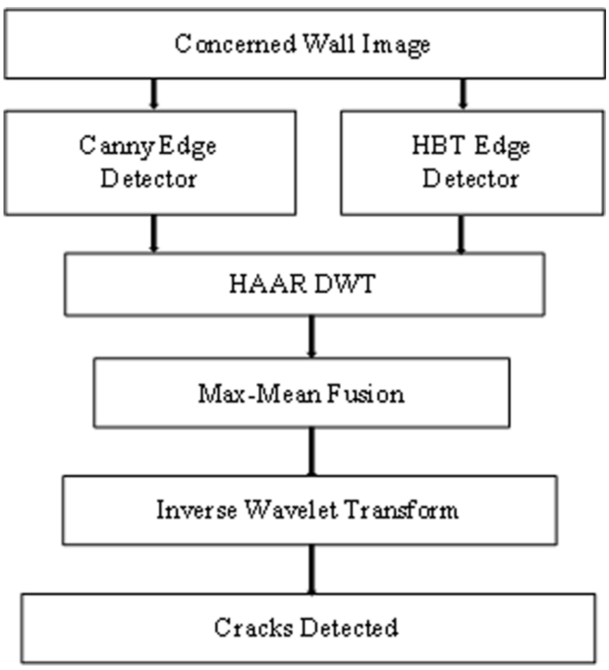

Fig .1 Proposed crack detection algorithm

(1) Acquisition of concerned wall image:-

Since the quality of detection result dominantly depend on the quality of the acquisition process, the choice of acquisition system must be done carefully. Normally image acquisition by means of 2D sensors needs image processing technique. In our experimental work , the cracked wall image sample is acquired by means of a camera with focal length of 4mm, exposure time: 0.002 sec, max aperture: 3.5. The lighting system should be designed in order to preserve the crack edges which may not well contrast and negligible as compared to wall image .The illumination problem can be solved by means of a stereoscopic system.

(2) Crack Detection:-

The edge detection algorithm [7] is based on the actual profiles of image edges and it optimizes only two of Canny's criteria i.e. accurate edge detection and localization. It doesn't include the third criterion- minimal response i.e. a given edge in the image should only be marked once, and where possible, image noise should not create false edges. So we have selected canny detector to fulfill the third criterion. Again from the spatial and frequency properties of HBT filter, It is clearly observed that the family of FIR HBT filters has a narrow bandwidth, indicating better noise reduction compared to Canny's Gaussian first derivative. Hence, our proposed edge detection architecture gives superior result by the fusion of common as well as complementary features of Canny and HBT based edge detection techniques.

(A) CANNY EDGE DETECTION

Canny considered three criteria desired for any edge detector such as good detection, good localization, and minimal response. The technique is basically known as feature synthesis. The image is smoothed using Gaussian convolution followed by a 2D first derivative operator. Then, nonmaximal suppression technique is applied using two thresholds. Usually for good result, the upper tracking threshold can be set quite high and lower threshold quite low [8]. A wide Gaussian kernel reduces the sensitivity of detector. The edge detected by canny operator are much more smooth and hence more tolerance to noise. So in this paper we have considered canny detector.

(B) HBT FILTERING EDGE DETECTION

An edge similarity measurement based algorithm by Saravana Kumar [7] gives superior result than GM and AN method. This technique is more rugged irrespective of diversity in illumination, contrast and noise level. The filtering technique basically highlights the edge similarities between image adjacency and directional finite impulse response by means of hyperbolic tangent figuration. This edge detection technique based on similarity measurement results an optimal identification of image edges by using principal component analysis. The Principal Component Analysis is applied to a set of local neighborhoods which can be expressed as

$$bi = m + \sum_{j=1}^{n^2} u_{ij} e_j \qquad (1)$$

Where u_{ij} is the projection of *bi* –m onto the *jth* Eigen vector e_j and *bi* is of size *n x n* .The PCA generates *n²* eigenvectors each of size *n* x *n* and { e_i *, 1 ≤ i ≤ n² }.*

The average value of all local neighborhoods (bi) is

$$m = \frac{1}{N} \sum_{i=1}^{N} b_i \qquad (2)$$

The Eigen values are in decreasing order of magnitude and eigenvector has similar characteristics as a low pass filter. The eigenvector pairs are orthogonal to each other. The PCA scheme is primarily based on successive approximation criterion. So, it gives an idea to use e_j values so as to minimize the approximation error. Starting with eigenvector pairs (*e2*, *e3*) and at higher ranges, it is found that, there is an accession of zero crossing points, which signifies that the lower range eigenvectors contains more clues regarding the local neighborhoods at high frequency ranges. . Since the Eigen vectors *e2, e3* assists in the accurate approximation process of local neighborhoods gray level alteration, our proposed model deals with eigenvectors *e2* and *e3* for crack edge identification. From Fig.6 and Fig.7, it is clear that e2 and e3 have blurred step edge profiles. Their approximated values are as follows:

$$\hat{e}_2 = \alpha_{21} h_1 + \alpha_{22} h_2 \quad \text{And} \quad \hat{e}_3 = \alpha_{31} h_1 + \alpha_{32} h_2 \qquad (3)$$

Where { α } are weights and HBT filter pairs h1 , h2 are determined from a set of four 2D HBT filters oriented along 0 degrees, 45 degrees, 90 degrees, and 135 degrees .

The HBT profile *h*1 w.r.t h2 is expressed as

$$G_w = \frac{1 - e^{\sigma_\omega (x+y)}}{1 + e^{\sigma_\omega (x+y)}} \quad \text{For } |x|, |y| \le W \text{ and 0 otherwise.} \qquad (4)$$

The region of support for Gw is confined within a window size W to guarantee edge identification. By the sampling process of Gw at integer positions in a period [-w, w], h1 and h2 filters are determined. The parameter σ_w determines the steepness of the profile at zero crossing. σ_w is determined for a given filter width W so as to best approximate the natural step edges in an image by means of the HBT filter pair correspondence to smallest $(\varepsilon_{total} = \varepsilon_2 + \varepsilon_3)$. The weights α_{ij} are determined by projecting both Eigen values e_2 and e_3 onto orthogonal HBT filter pairs h1 and h2, i.e.

$$\alpha_{ij} = \frac{\langle e_i , h_j \rangle}{\langle h_j , h_j \rangle} \qquad (5)$$

The approximation error is given as

$$\varepsilon_i = \frac{\| e_i - e_j \|}{\| e_j \|} \qquad (6)$$

Here the extra sensitivity to illumination can be mitigated by modifying their edge-similarity measure with Ri with regularization parameter **γ**, an empirical constant **c**. The Ri is expressed as,

$$R_i = \frac{\langle b_i - \overline{b_i} + c\gamma , g \rangle}{\| b_i - \overline{b_i} + c\gamma \| . \| g \|} \qquad (7)$$

An estimate $\overline{\gamma}$ *,* obtained by mean absolute deviation is given by

$$\overline{\gamma} = \frac{median(Y_i : 1 \le i \le N)}{0.6745} \qquad (8)$$

$$\text{Where } Y_i = \sqrt[2]{\frac{1}{n^2} \sum_{j=1}^{n^2} \left[b_i(j) - \overline{b_i} \right]^2} \qquad (9)$$

i=1, 2… N.

Applying Ri to the sample wall image to compute four similarity maps where each map corresponds to one of the four HBT filters equivalent similarity map is determined. By means of suitable threshold value on local maxima, the edge pixels are determined.

(3) Wavelet Decomposition and Fusion:

After detection of crack edges by the different detectors, the next key issue is the type and level at which the image fusion takes place. The wavelets-based approach is appropriate for performing fusion tasks due to its multiresolution characteristics to deal with images at varying resolution as described by Pajares et al. [9]. The discrete wavelets transform (DWT) performs the image decomposition in different kinds of coefficients preserving the original information of an image. The iterative decomposition helps in increasing the frequency resolution. The approximation coefficients are then disintegrated through high and low pass filters along with the down sampling operation as shown in fig.2.

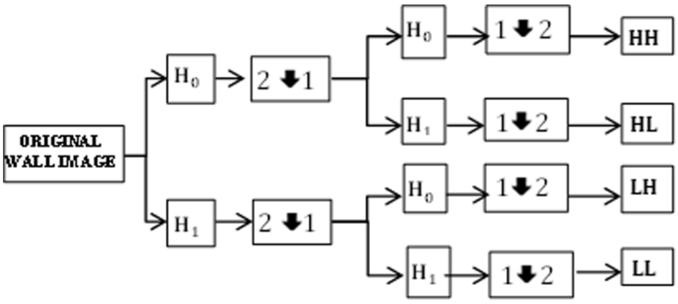

Fig.2 Discrete wavelet filter banks

In the comparative study of image fusion algorithms by S. Krishnamoorthy et al.[10], Haar Discrete Wavelet Transform based fusion method was evaluated as the outstanding method in terms of subjective analysis. Like all wavelet transforms, the 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 sub signal is a running difference or fluctuation. Some of the exclusive aspects of Haar wavelet transform are its efficient processing speed, simplicity, memory management and reversibility. The Haar wavelet's mother wavelet function $\psi(t)$ can be described as

$$\psi(t) = \begin{cases} 1 & 0 \le t \le 0.5 \\ -1 & 0.5 \le t \le 1 \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Its scaling function $\phi(t)$ can be described as

$$\phi(t) = \begin{cases} 1 & 0 \le t \le 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

The 2×2 Haar matrix associated with the Haar wavelet is

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{12}$$

The coefficients derived from input images can be suitably integrated to acquire new coefficients; retaining crude information of the original images. Once the coefficients are merged, then fused image is achieved through the inverse discrete wavelets transform (IDWT), where the information in the merged coefficients is also preserved. The key step in image fusion based on wavelets is to merge coefficients in an appropriate way in order to obtain the best quality in the fused image. The hybrid fusion algorithm [11] combines the advantages of both pixel and region based fusion by selecting maximum approximations, averaging of detail coefficients.

III. RESULTS & DISCUSSION

In this edge detection technique the concerned wall image acquisition is done by means of a camera with focal length of 4mm, exposure time: 0.002 sec, max aperture: 3.5. The image is resized to 256X256 for ease of processing and is shown in Fig.3. Our proposed method is based on crack detection process using two efficient and reliable edge detection algorithms such as canny edge detection and HBT filtering. Canny detector response fulfills the three criteria desired for any edge detector such as good detection, good localization, and minimal response as shown in Fig.4; whereas HBT filtering technique highlights the edge similarities between image adjacency and directional finite impulse response as shown in Fig.5. In the Fig.6, 7, the second and third largest PCA Eigen values are plotted in spatial domain respectively. The Total error vs. σ_w plot in Fig.8 shows that σ_w value of 0.48 best approximates the natural step edges in an image by means of the HBT filter pair correspondence to smallest approximate error value of 0.1680. We have considered three levels Haar DWT decomposition technique shown in Fig.9 using Graphical User Interface (GUI). In the next stage, the decomposition results of individual cracked images are fused using an efficient fusion rule. Here we have selected maximum-approximation and mean-detail fusion selection algorithm. The high pass filter mask enhances the edges whereas averaging filter mask helps in removing noise by taking mean of gray values surrounding the center pixel of the window. Finally by the application of Inverse DWT, the synthesized fused image is recovered to identify the cracks more accurately. The proposed crack detection technique produces a crack detected image with improved PSNR, Entropy, Normalized Absolute Error value and the Feature Similarity Index (FSIM), which is based on phase congruency. The performance metrics is shown in Table. I. Here the overlapped crack edges of both detectors highlight the genuine crack locations in the original image avoiding the false edges which is shown in Fig.10.

Fig.3 Original Wall image showing a hairline crack

Fig.4 Canny Edge detector response

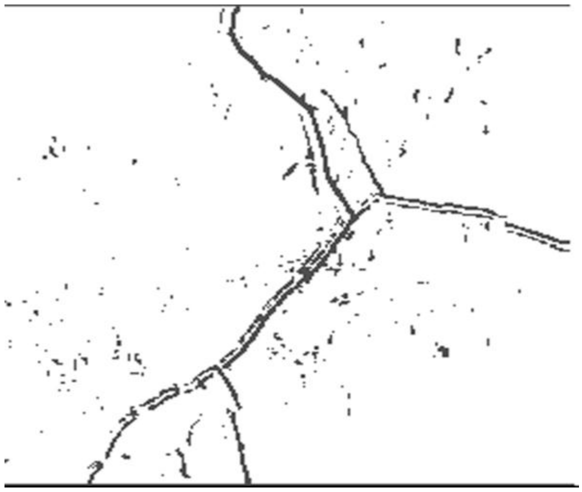

Fig.5 HBT filter response with sigma = 0.48
Totalminerror = 0.168, gamma = 0.0208, Threshold = 0.83

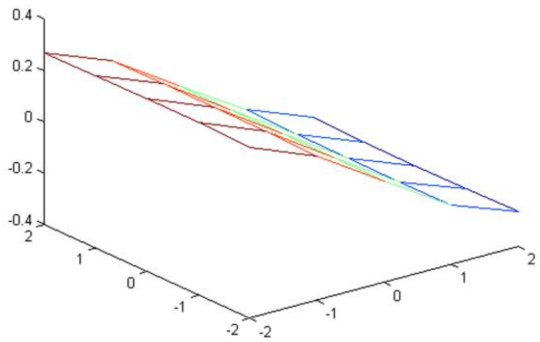

Fig.6 Second largest PCA Eigen values in spatial domain for wall image

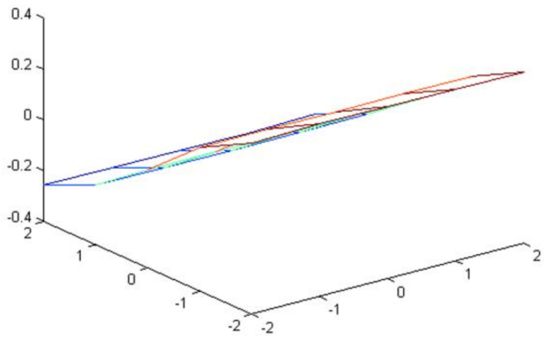

Fig. 7 Third largest PCA Eigen values in spatial domain for wall image

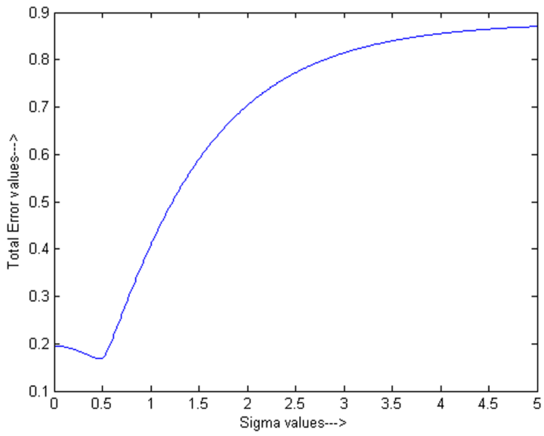

Fig.8 Totalminerror as a function of σ_w

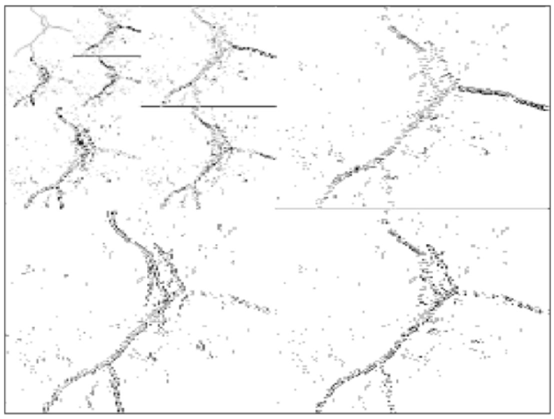

Fig.9 Fusion with 3 level Haar DWT decomposition using GUI

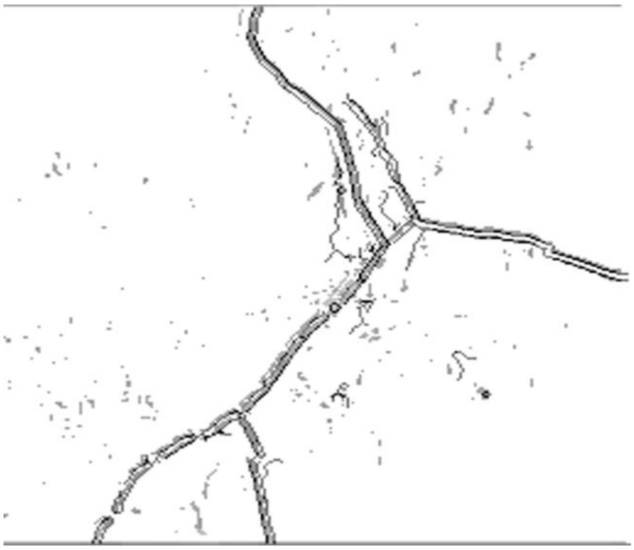

Fig.10 Image Fusion Response using GUI

Table I Performance Metrics

Quality Indices / Methods	PSNR (dB)	JOINT ENTROPY	NORMALIZED ABSOLUTE ERROR	FSIM
Canny Edge Detector	10.5183	5.9816	0.3947	0.6429
HBT Edge Detector	10.8215	6.1161	0.3875	0.6319
Proposed Technique	11.1523	6.4054	0.3699	0.6602

IV. CONCLUSIONS

In this paper, we proposed novel crack detection technique based on two efficient crack detection algorithms along with an efficient image fusion by means of Haar discrete wavelet transform. HBT filtering method emphasizes on optimization of two of Canny's criteria- accurate edge detection and localization, without explicitly including the minimal response criterion and Canny Edge detector avoids the false edge detection. In our proposed technique for crack detection, both Canny and HBT based filter responses are fused together resulting an optimized edge detection technique. Here, we have chosen maximum-approximation and mean-detail fusion selection algorithm. The high pass filter mask enhances the edges whereas averaging filter mask helps in removing noise by taking mean of gray values surrounding the center pixel of the window. Here the image fusion response is having higher values of PSNR, Entropy and Feature Similarity Index as compared to canny as well as HBT edge detector responses. The Normalized Absolute Error also gets reduced. Finally, the smoothness parameter should be taken relatively high value to decrease the slope of the filter function reducing the oscillations of the filter response function in the time domain.

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