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Detection and Analysis of Surface Defects in Metals Using Wavelet Transform

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Abstract- Surface tribology and metrology are one among the challenging tasks in the field of image processing and has extensive applications. Structural damage is one of the factors that causes machine breakdown. This paper is intended to propose a new method for explicit analysis of surface defects. In this proposal, the images are acquired using a Panasonic BB-HCM381 camera. These images are subjected to 2 dimensional discrete wavelet transform which uses sub band coding algorithm for feature extraction. The analysis of surface fissures is rendered by obtaining numerical data from the image. This data aids in performing statistical analysis that involves the calculation of mean, variance, standard deviation, skewness and kurtosis from the acquired image. These parameters are calculated for different wavelets like HAAR, Daubechies and a comparative study is made. LabVIEW is the system design platform used for developing this application.

Index Terms- 2D Wavelet transform, denoise, edge detection HAAR Wavelet, LabVIEW, Thresholding

I. Introduction

Nondestructive visual inspection techniques are in high demand for damage detection and localization. The process of manual inspection is very risky, labor intensive and tends to be erroneous since it purely depends on the psychology and experience of the human observers and is often influenced by his prior knowledge about the object under inspection. As visual monitoring systems require same type of images over and over again to recognize anomalies, an automated surface inspection technique is the only immediate alternative to human inspector in order to detect the abnormalities which deviate from the actual pattern. The surface defects generally result from textural irregularities on the outer surface. Hence, anomalies on surface are the main concern for visual surface inspection techniques. These methodologies have innumerous applications on various surfaces like wood, steel, wafer, ceramics, etc., yet they have extensive applications in industries in condition monitoring of machineries.

The term “machinery failure” indicates that the equipment has ceased to perform the way it was designed for. This is termed as “loss of usefulness”. This loss of usefulness is an aftermath of the following phenomena: obsolescence (15%), surface degradation (70%) and collisions (15%). Among these three, surface degradation contributes to the majority of this loss based on this statistical data. Surface degradation constitutes mainly of corrosion (20%) and mechanical wear (50%).

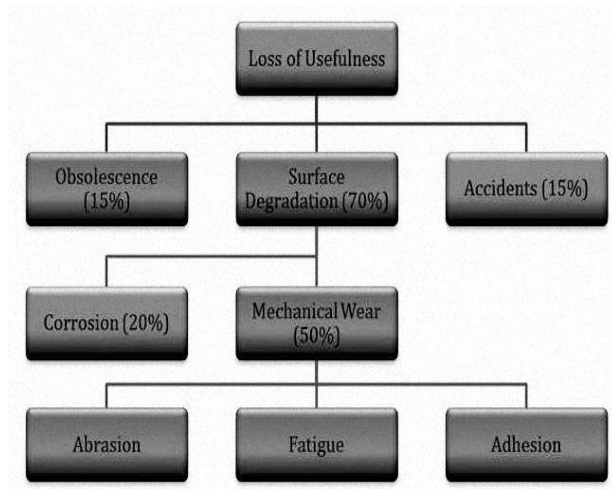

Fig.1. Causes of Machine Failure

The acids formed as a by-product of extreme pressure additives like oil leads to corrosive wear. Mechanical wear results from mechanical stroking or rubbing of machine surfaces with neighboring surfaces. Mechanical wear is the consequence of three actions – abrasion, fatigue and adhesion. Abrasive wear is a method in which contamination of particles causes majority of the wear. Adhesive wear incorporates two surfaces drawing into immediate contact with each other, delivering material from one face to the other. Metal fatigue is the phenomenon of aging of metal which is caused due to continuous cycles of stress on the metal. From all the statistical data furnished, it is evident that surface degradation is the factor that accounts for majority of machine failures.

Usually textures are classified into two types: structural and statistical. Structural textures are formulated by iterations of basic texture primitives such as oriented lines, with deterministic rules of displacement. Statistical texture cannot be explained with deterministic rules of displacement. This paper is concerned about developing a discrete wavelet transform technique to diagnose the defect in machineries. The prototype of an inspection system designed for monitoring using machine vision and the various image processing techniques used to inspect anomalies are presented.

II. EXISTING SYSTEM

A. Principle of operation

In conventional methods, structural damage in an image is detected using ultrasonic inspection. This technique uses high frequency sound waves for surface monitoring. For eg, ultrasonic steel testing is performed at 1 to 5 MHz. The frequency range for ultrasonic testing stretches from 200 KHz to 15 MHz. In ultrasonic inspection, sound energy was made to propagate through the object in the form of waves and any discontinuity in the wave signal signifies a crack or structural damage. This interruption is the effect of reflection of partial energy back from the flawed surface.

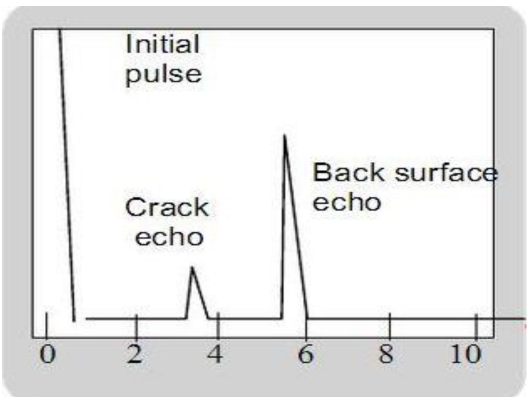

Fig.2. Ultrasonic Testing

B. Disadvantages in existing system

The Ultrasonic non-destructive testing system is a convenient and beneficial method since it has a very high sensitivity and penetrating power which assists in minute flaw detection. Yet, Ultrasonic NDT has its own limitations. This technique is incompatible for non-homogenous surface. Inspection of cast iron and other coarse grain materials are strenuous because of minimal acoustic transmission and maximum signal noise. The Ultrasonic NDT fails to detect the linear flaws that are oriented parallel to the Ultrasonic waves.

III. 2D WAVELET TRANSFORM

Due to a number of drawbacks in this method, we propose a method to detect the structural damages of a metal using wavelet analysis. The fundamental idea behind wavelet transforms is to produce smoothing and differencing operations and, at each level, maintain the same number of pixels as the original image.

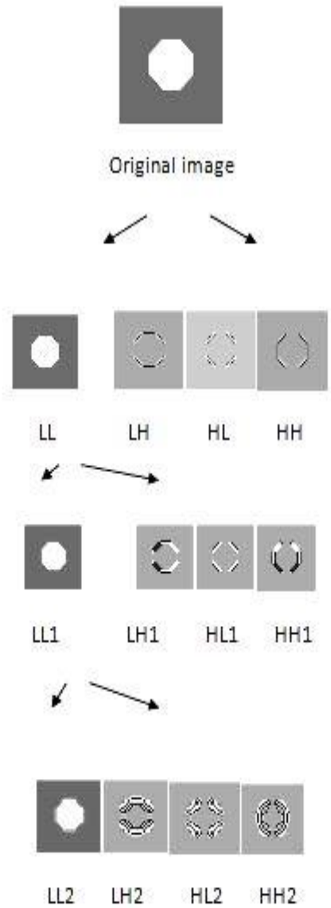

Fig.3. 2D Wavelet Transform

At Level 1, the image is smoothed and reduced to a 1/4 size of the original image producing a lower resolution version (Low_Low or LL), and 3 different local differencing operations are performed, providing edge detection of 3 kinds: horizontal component images (Low_High or LH), diagonal component images (High_Low or HL), and vertical component images (High_High or HH). The total number of pixels at this level is equal to that of the original image. Moreover, this Level 1 transform can be inverted: From the 4 sub images at Level 1, the original image can be reconstructed.

Level 2 of a wavelet transform repeats the averaging and differencing operations on the Level 1 smoothed sub image. This iterative process continues. We have stopped in Fig. 4 at Level 3. The Level 3 transform consists of a 1/64 size smoothed sub image, and all of the edge sub images created by local differencing at each level. The original image can be recovered from this 3-Level transform.

IV. HARDWARE AND SOFTWARE DESCRIPTION

A. Hardware used

Images are captured using the CCD camera of type Panasonic BB-HCM381.

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Fig.4. Camera used- Panasonic BB-HCM381

A table mounted camera captures the image with a pan of 360° (-175° up to +175°in horizontal direction) maximum display range and tilt of 158° (-120° up to 0° in vertical direction) maximum display range. We use a PC or cell phone directly to change the direction of the camera while monitoring the image. This lets us monitor a large area with a single camera in JPEG standard. Image gets sampled at a rate of 12 frames/sec for the resolution of 640x480 and 30 frames/sec for the resolution of 320 x 240 and 160 x 120. The viewing angle for the camera are as follows: Horizontal: 2.6° (optical) /1.3° (digital) wide: 51° and Vertical: 1.9° (optical) /0.9° (digital), wide: 38°.The camera has a 42x zoom capacity (21x optical, 2x digital)[2] .

B. Use of Simulation software – About LabVIEW

LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a system design platform and development environment for a visual programming language from Instruments. LabVIEW is a comprehensive development environment that provides engineers and scientists unprecedented hardware integration and wide-ranging compatibility. LabVIEW through its unique graphical programming environment; built-in engineering-specific libraries of software functions and hardware interfaces; and data analysis, visualization, and sharing features helps in reduce time.[10]

V. HAAR WAVELET

Haar wavelet is very effective in edge detection.The Haar wavelet is a sequence of rescaled "square-shaped" functions which together form a wavelet family or basis. Wavelet analysis is similar to Fourier analysis in that it allows a target function over an interval to be represented in terms of an orthonormal function basis. The Haar sequence is now recognised as the first known wavelet basis and extensively used as a teaching example. Haar used these functions to give an example of a countable orthonormal system for the space of square-integrable functions on the real line. The study of wavelets, and even the term "wavelet", did not come until much later .

The technical disadvantage of the Haar wavelet is that it is not continuous, and therefore not differentiable. This property can, however, be an advantage for the analysis of signals with sudden transitions, such as monitoring of tool failure in machines [3].

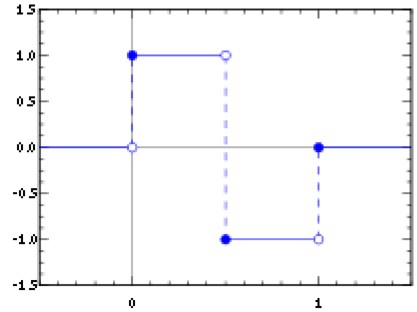

Fig.5. HAAR Wavelet

The Haar wavelet's mother wavelet function $\psi(t)$ can be described as

$$\psi(t) = \begin{cases} 1 & 0 \le t < 1/2, \\ -1 & 1/2 \le t < 1, \\ 0 & \text{otherwise.} \end{cases}$$

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

$$\phi(t) = \begin{cases} 1 & 0 \le t < 1, \\ 0 & \text{otherwise.} \end{cases}$$

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 subsignal is a running difference or fluctuation [9].

A. Denoise

[1] Although other types of noise (e.g., impulse or Poisson noise) have also been studied in the literature of image processing, the term “image denoising” is usually devoted to the problem associated with AWGN. Mathematically, if we use Y=X+W to denote the degradation process (X: clean image, Y: noisy image, $W \sim N(0,\sigma_w^2)$), the image denoising algorithm attempts to obtain the best estimate of X from Y. The optimization criterion can be mean squared error (MSE)-based or perceptual quality driven [4]. This VI in the labview completes the following steps to implement the noise reduction for signals and images using wavelet transforms. Firstly, it applies the wavelet transform to the noisy data and obtains the detail coefficients and the approximation coefficients. Then we apply soft or hard thresholding to the resulting coefficients, thereby suppressing those coefficients smaller than a certain threshold. The thresholding rule and the rescaling method determine the threshold. Finally we reconstruct the coefficients after thresholding and transform them back into the original domain. To perform denoising on complex signals, use the UWT method. The DWT is more efficient for decomposing signals, but the UWT provides better denoising performance because it can help reduce artifacts, such as Gibbs oscillation.

B. Edge Detection using Thresholding

Thresholding is the simplest method of image segmentation. From a gray scale image, thresholding can be used to create binary images. During the thresholding process, individual pixels in an image are marked as "object" pixels if their value is greater than some threshold value (assuming an object to be brighter than the background) and as "fault" pixels otherwise. An object pixel is given a value of "0" while a fault pixel is given a value of "1" [4].

C. Experimental Setup

Image is acquired using CCD camera of type Panasonic BB-HCM381 from any structures and further processed using DWT algorithm. Before further processing the image is denoised and MSE is calculated. PSNR is calculated for the original and image after denoising. When PSNR is 40dB or higher, then the original and the reconstructed images are virtually indistinguishable by human observers. DWT algorithm is an effective algorithm to identify defects in these images.

VI. FEATURE EXTRACTION

The key parameter in the thresholding process is the choice of the threshold value which can be computed by calculation of mean and standard deviation. For this purpose the various features such as minimum, maximum , median , mean , standard deviation are calculated from the resultant image .The features are calculated for the whole image [8].

The minimum for image f(x,y) can be calculated as
Minimum=Min (f(x, y)) (1)
x=1,2,…M
y=1,2,…N

The maximum point can be calculated for the image f(x, y) as
Maximum=Max (f(x, y)) (2)
x=1,2,…M
y=1, 2,…N
where x and y varies in both (1) and (2)

Mean is generally a measure of spread, in image processing mean helps in measure of location.The mean value of image f(x, y) can be calculated as

$\mu = \sum f(x, y)/(M \times N)$
x =1, 2,…M
y=1, 2,…N
x and y varies to identify the intensity of each pixel.

The standard deviation of an image f(x,y) can be calculated as

$$\sigma = \sqrt{\frac{\sum f(x,y) X D}{M X N}}$$

x =1,2,…M y= 1,2,…N

Peak Signal to Noise ratio(PSNR) used to be a measure of image quality. The PSNR between two images having 8 bits per pixel or sample in terms of decibels (dBs) is given by:

$PSNR = 10 \log 10 (255^2/MSE)$

Where MSE is mean square error.

Mean squared error (MSE) is defined for two $m \times n$ monochrome images I and K where one of the images is considered a noisy approximation of the other is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

STATISTICAL PARAMETER FOR IMAGES WITHOUT CRACK

	ORIGINAL	DENOISE	RECONSTRUCTED	LL	LH	HL	HH
MEAN	190.657143	190.412905	190.41290	380.7409	0.090434	-7.53E-16	1.96E-16
STANDARD DEVIATION	23.337749	21.16862	21.16862	40.80042	11.33717	6.64E-15	7.45E-15
VARIANCE	544.650549	448.110475	448.110475	1664.674	128.5315	4.41E-29	5.56E-29
SKEWNESS	0.884207	0.972111	0.972111	0.819976	1.83541	0.01515	-0.49497
KURTOSIS	3.413185	3.396065	3.396065	2.970318	13.76858	4.244779	3.360389

STATISTICAL PARAMETER FOR IMAGES WITH CRACK

	ORIGINAL	DENOISE	RECONSTRUCTED	LL	LH	HL	HH
MEAN	180.945	181.6617	181.6617	363.3234	0.11	1.69E-16	-1.19E-15
STANDARD DEVIATION	14.29488	13.08342	13.08342	25.63471	5.568723	6.08E-15	6.60E-15
VARIANCE	204.3437	171.1758	171.1758	657.1382	31.01067	3.69E-29	4.36E-29
SKEWNESS	0.211185	0.143771	0.143771	0.088617	-1.59051	0.159933	-0.2662
KURTOSIS	2.530556	2.524504	2.524504	2.470523	12.38489	2.933341	2.773746

Fig.6. Statistical Parameters for images with and without crack

Generally when PSNR is 40 dB or greater, then the original and the reconstructed images are virtually indistinguishable by human observers.
The table illustrates the mean, standard deviation, variance, skewness and kurtosis values taken for uncracked and cracked images. It can be observed that the values for cracked image are of lower values due to lower pixel values.

Table.1 PSNR and MSE for original and denoised image

	PSNR	MSE
ORIGINAL	16.102	1849
DENOISE	16.2781	1721.79

VII. FEATURE EXTRACTION

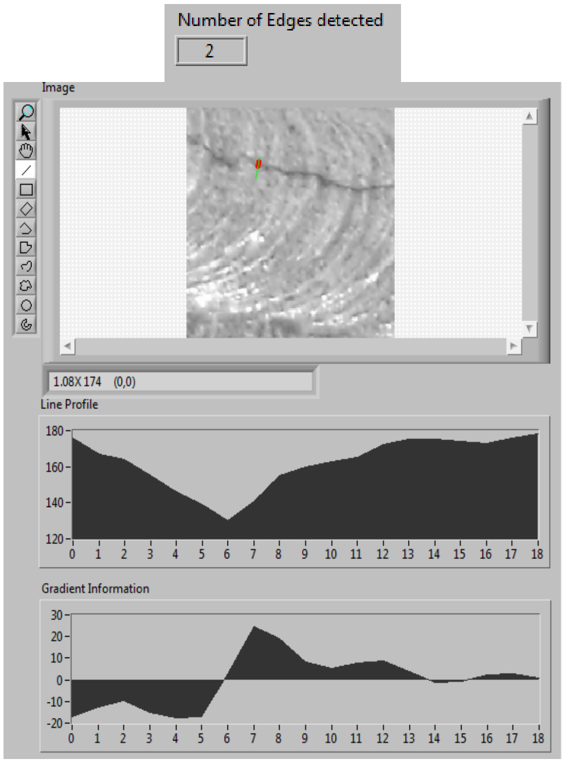

Fig.7. Line Profile graph

Finding the angle of inclination of the crack from the surface is a important feature to analyze the crack. The following procedure describes the methodology use to calculate the angle of inclination of crack. Line profile and gradient information are used for the analysis.

20 samples are selected from the image so as to cover the crack entirely. From the gradient information for those 20 samples, minimum and maximum values are noted.

A value A is calculated by finding the difference between the maximum and minimum values obtained. Mean value of A is calculated for 20 samples. The angle of inclination at each and every one of the sample is calculated by subtracting the calculated mean value and the minimum value.

SAMPLE NO.	MINIMUM	MAXIMUM	A= MAX-MIN	ANGLE=MEAN-MIN
1	-50	25	25	102.25
2	-20	20	40	72.25
3	-25	10	35	77.25
4	-30	50	80	82.25
5	-30	30	60	82.25
6	-30	20	50	82.25
7	-20	10	30	72.25
8	-15	25	40	67.25
9	-25	18	45	77.25
10	-30	38	68	82.25
11	-35	10	45	87.25
12	-25	20	45	77.25
13	-40	20	60	92.25
14	-30	20	50	82.25
15	-28	18	46	80.25
16	-38	20	58	90.25
17	-12	7	19	64.25
18	-38	38	76	90.25
19	-30	20	50	82.25
20	-35	38	73	87.25
MEAN VALUE = 52.25				

Fig.8. Angle of Inclination

VIII. SUPPORT VECTOR MACHINE

Support Vector Machine (SVM) performs classification by constructing an N-dimensional hyper plane that optimally separates the data into two categories. SVM models are closely related to neural networks. In fact, a SVM model using a sigmoid kernel function is equivalent to a two-layer, perceptron neural network[11]. Features such as mean, standard deviation, variance, skweness and kurtosis of a uncracked and cracked image are used to classify the good and bad data.The figure illustrates the classification based on features of uncracked and cracked image given as a input.The data is classified using a kernal function.

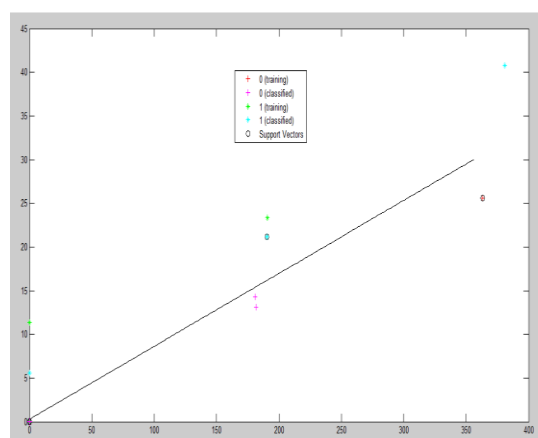

Fig.9. Kernel function

XI. RESULTS AND DISCUSSIONS

Detection of crack is the most important criterion. We use Discrete Wavelet Transform to split the images (LL, LH, HL and HH). The figure shown below shows the result of Discrete Wavelet Transform.

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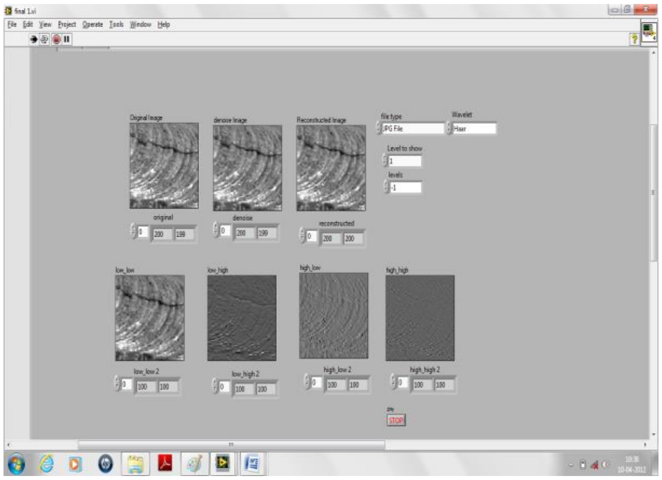

Fig.10. Front panel – Wavelet Transofrm

From the figure it can be inferred that the welding flaw is visible clearly in LH displaying the horizontal cracks.

1 D and 3D wavelet coefficient plot helps us to analyse the crack. By applying the threshold calculated by taking the difference of mean and standard deviation, the crack in the image is isolated from the surrounding.

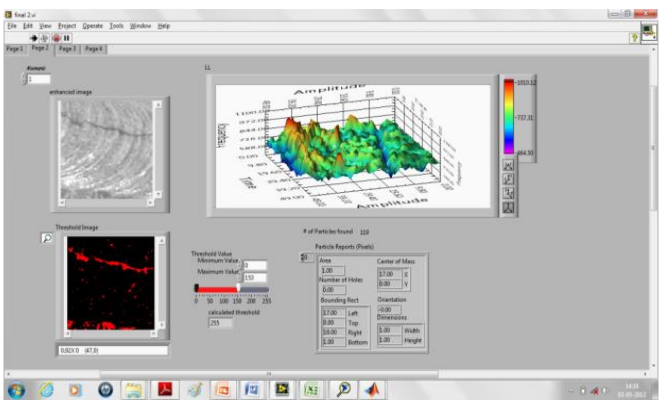

Fig.11. Front Panel - Thresholding

IX. CONCLUSION

In testing of welding flaws, the reliability and quality of tests are considerably affected by noise and spurious signals. Thus, signal de-noising and increasing of the signal-noise ratio (SNR) are a key to successful application. Using discrete wavelet transform the flaw has been isolated using threshold of the transformed image and different statistical features have been studied.

APPENDIX

Appendixes, if needed, appear before the acknowledgment.

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in American English is without an “e” after the “g.” Use the singular heading even if you have many acknowledgments.

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