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Ceramic Tiles Defect Detection Using High Frequency Subband Feature Selection Based on Un-decimated discrete wavelet Transform

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Abstract : Quality control is a significant problem in the ceramic tile industry and maintaining the rate of production with respect to time is also a main problem in ceramic tile manufacturing industry. Therefore, the price of ceramic tiles depends upon the clarity and accuracy of color, texture, shape etc. Hence, in this paper proposing an approach for automatic ceramic tiles defect detection and classification using digital images capturing from real ceramic tiles. High resolution camera is used for capturing the tiles images. Sobel based edge detection method used for segmentation and Un-Decimated Discrete Wavelet Transform (UDWT) is employed to acquire the HH high frequency subband for ceramic tiles image. Then GLCM and Gabor filter is employed to the latter at various frequencies to extract the features. Finally, classification of given ceramic tile features is performed using the Artificial Neural Network (ANN). This proposed system intended the work of surface defects detection on ceramic tiles with more accuracy and minimized time. These defects are broken corners and edges, Cracks, Lines, Pinholes etc., which are present on the ceramic tiles. The proposed approach ensures the better quality of tiles in manufacturing process and it is helpful for ceramic tile industry as well as improves the production rate.

Keywords : Tiles defect detection, Undecimated discrete wavelet Transform (UDWT), Artificial Neural Network (ANN), Sobel based edge detection.

1. INTRODUCTION

In recent research fields, image processing is one of the enhanced fields. As technology improves, the analog imaging system is moved to the digital imaging system and image processing applications are also growing rapidly. Digital image processing is utilized to extract different kinds of features from images by computer systems automatically without any human interventions [1]. The most significant operation in digital image processing is to identify and classify different types of defects. Thus, identification of such defects from any image using various methods are discussed and established at three levels. Initial level deals with raw data without considering the noisy pixel values, in this stage done different operation, for example de-noising and edge detection [2]. The middle stage utilizes the results of the initial level and performs segmentation and edge linking operation. At the final stage, these approaches attempt to extract semantic meaning of the data provided by the initial level.

Ceramic tile manufacture is one of the significant industries in manufacture industry. All the tile manufacturing phases are technically maintained from initial stage to final stage. Frequent inspections are required for the ceramic tiles to satisfy the customer needs, it means to find the defected tiles. Hence the classification of ceramic tiles based on the surface is a significant process after production. The manual defect detection approach is slow, labor intensive and subjective. Even though automated packing and

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sorting lines have been in survival for a number of years, the inspecting complexity of selecting damage tiles is against the standard of a manufacturer which means automatic tile inspection is not been possible [3]. Thus, the expert judgment is utilized by prior knowledge and expectations. In numerous detection tasks such as noise reduction, edge detection, etc., there is a continuous growth from presence to absence [10] [11] but cannot identify the correct structure. Therefore a monitoring task is expensive, course tedious and subjective. For all these soundness no one can refuse the importance of automated ceramic tiles defect classification and detection system. The objective of this research work is to propose an efficient automatic ceramic tiles defect classification and detection technique. The quality of tiles refined using feature extraction factors and additionally the filtering stage using a combination of GLCM metric and Gabor filter is utilized to acquire proper enhanced features. This system able to find out ceramic tiles image defects at a high rate within a short period of time.

The outline of this paper is as follows. Section 2 briefly reviews the existing ceramic tile defect detection works. Section 3 shows proposed method material and methods. Section 4 shows the experimental results and comparison. Finally, section 5 provides concluding remarks.

2. RELATED WORK

The automatic classification system plays a vital role in different sorts of industries. Thus, in ceramic industry, the classification of ceramic tiles is a challenging task as it has an enormous variation of surface characteristics. Therefore, the author proposed a new automatic surface classification system using Discrete Wavelet Transform (DWT) and Level Co-occurrence Matrices (GLCM) [4]. The ceramic tile texture information's are represented by DWT at different decomposition levels. The energy features are extracted by using DWT and also correlation, statistical features, contrast, homogeneity and energy are extracted from the ceramic tiles by using GLCM. Finally, Feed Forward Neural Network (FFNN) classifier is used for the classification process. The VxC TSG image database is employed in the evaluation process.

The rapid development of utilizing image databases in the image processing field, for example multimedia, medical science, geographical information system, journalism, photography etc. An efficient method is needed to process the images. One of the image processing techniques is content based image retrieval which is used for content based extraction like color, texture, spatial layout and shape [5]. However, it is a very challenging process to retrieve the image because of their semantic gap between low-level features and user's high level concepts. In order to reduce this gap numerous concept was introduced. But the texture based feature extraction brings the prominent results.

Growth of an automatic defect detection approach has a major influence on the performance of ceramic tile industry. Thus, in [6] a new algorithm has been employed for random texture tiles defect detection based on segmentation approach. Firstly, Undecimated Discrete Wavelet Transforms (UDWT) is used for extracted the frequency features of textures from tile image. Then texture information is extracted by using a co-occurrence matrices, Finally, a Back Propagation Neural Network is employed for segmentation by using combination of co-occurrence metrics and texture features. The experiment results are showing a higher accuracy while utilizing co-occurrence and conventional wavelet method.

Marble tile inspection method [7] was proposed where the linear CCD camera is used for capturing the marble image running on a conveyor belt and being utilized for geometrically inspection within 300 msec. Supporting algorithm is used for accommodating tiles of any color and sizing with fully functional, fast, proof. Since the entire system is fully automated and utilized by inexperienced personnel, the proposed algorithm automatically checks the CC array problems, for example, on the housing or dirt on the sensor itself and burned pixels. The algorithm also takes an account of the cropped image from database storage. The robust least squares method is used to extract from edge line and edge pixel. Line intersection approach is used for detecting corners of the tiles and geometrical characteristic calculation. Finally, the projective transformation such as misalignments, size uniformity and adjust rotation is performed using the cropping operation.

In [8] ceramic tiles defect detection and classification based on the image processing method is proposed. The Pythagorean Theorem is used for ceramic tiles corner defect classification by using square ceramic titles.

In [9] a classification method has been proposed to defective and normal tiles classification using artificial neural networks and wavelet transform. The proposed method calculates standard deviation as well as the max and min medians, and average of details image acquired form wavelet filters, then Perceptron neural network with a single hidden layer is used for classifying the give tiles by using feature vectors. In this approach the basic feature is the median of optimum points and which compares to the statistical features in wavelet filed by making use of the Haar Wavelet approach. The experimental results show 90% cases are given valid results.

3. MATERIAL AND METHODS

A. Camera setup and Image acquisition

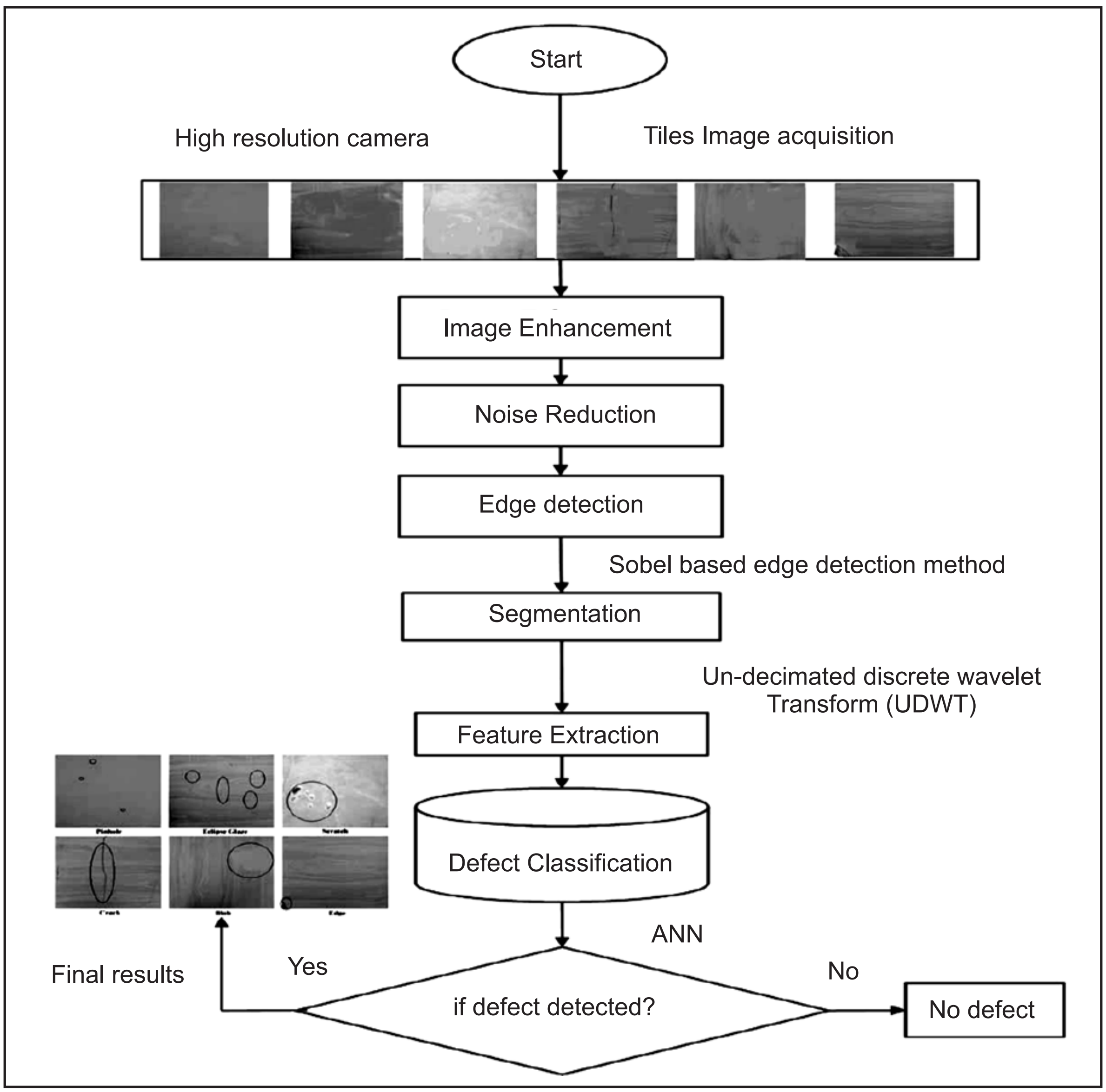

Figure 1: Tiles Image Defect Classification System

A 2098 pixel line scan color CCD camera is used in this proposed approach; the tile defect detection application commonly uses the line scanners because of their high efficiency. A 28mm macro lens camera was used; the lens setting differs from maximum exposure time, thickness of tiles and assures reliable lighting conditions, so that all the tiles have same constant and an illumination appearance in the images. In image acquisition process, a mechanical sensor is used at the time of the initial stage, which means the process start just before tiles enter the region view of the liner CCD camera. 300mm long tiles are captured by 1200 lines, as ensures that the entire tiles would be captured.

The CCD camera provides offset and gain control per color channel like R-G-B, offset and gain values and also exposure time were modified at the time of system setup. This system setup happens each time when a new tile sort is introduced to the system and it is an iterative procedure, including acquisition of 2^{nd} and 3^{rd} images of sample tiles illustrative of the batch. The proposed tiles image classification system is shown in Figure 1.

B. Contrast Enhancement and Noise Removal

Most of the time images taken from CCD camera are very dark due to a wrong setting of the lens or lack of dynamic range of the imaging sensor and poor illumination. The contrast of the image pixel is enhanced by using contrast stretching approach which obtains the image. This process is making use of reliable and appropriate feature extraction. The contrast stretching enhances the processed image intensity level in dynamic range. The Adaptive histogram equalization technique is used for the contrast enhancement process. It divides the image into multiple local regions from which each pixel is calculated by using the following equation

$$P_{out} = (P_{in} - c)\frac{(b-a)}{(d-c)} + a \quad (1)$$

Where P_{out} denotes the normalized pixel value, P_{in} denotes the current pixel value, b is the upper pixel value, a is the lower pixel value, d denotes the highest pixel value of input image and denotes the lowest pixel value of input image.

The basic idea behind this Histogram Equalization (HE) is the transformed images are in a uniform way. Let $f(x, y)$ is an image and its histogram is defined as $h(i)$, which is calculated by using following equation

$$c(i) = \int_o^i h(t)dt \quad (2)$$

The transformation variable $y = c(i)$ is uniform distributed, thus the HE can performed by using below equation

$$f = \frac{256}{m} * c(f(x, y)) \quad (3)$$

Where m is the total number of image pixels.

The image has some kind of disturbance called noise. It may be because of the wrong settings of camera lens, movement of the camera on the object and low contrast etc. The some unwanted pixels are increased by the noises. This leads to false region-of -interest detection. The image filtering operation like rank selection (RS) filter for example median filter is used in this approach. This median filter method is good at the removing salt and pepper noise from the ceramic tiles images.

$$y[m, n] = \text{median}\{x[i, j],(i, j) \in w\} \quad (4)$$

Where w denotes a neighborhood of (m, n) image pixels.

Edge detection is the one of method for detection of meaningful image shape. An edge may be connected as a two dissimilar regions boundary and this may differ from surface of the object or a boundary between shadow and light falling on the image surface. However, the edge detection approach classified as two subgroups such as gradient and Laplacian method [12]. The gradient approach detects the edges by using minimum and maximum value in the first order derivation of the image and the Laplacian method utilizes a second order derivation method using search zero crossing in the image. The Gradient method used in this proposed system and the gradient direction $\theta(x, y)$ is calculated as

$$g(x, y) \cong (\Delta x^2 + \Delta x^2)^{\frac{1}{2}} \quad (5)$$

Where $\Delta x = f(x + n, y) - f(x - n, y)$ and $\Delta y = f(x, y + n) - f(x, y - n)$

C. Sobel based edge detection method

The sobel based edge detection method is commonly used for edge detection where as in the proposed system, it is used for segmentation. The segmentation is the process of extracting regions of interest from captured image or extracting features for additional intelligent computer analysis. A different kind of image properties is used in this system such as texture, intensity, global statistical or position or some local parameter. The given image is segmented into multiple regions based on these properties of the pixels.

Here, the edge detection sobel operator based segmentation process is defined as follows

Sobel based edge detection method for Segmentation

Step 1: Read ceramic tiles image

Step 2: Apply into vertical mask G_y and horizontal mask G_x to the ceramic tiles image

Step 3: Employ gradient results and find sobel edge detection as

$$|\nabla f| = |G_x| + |G_y|$$

Step 4: Create separate image for G_y and G_x

Step 5: All the results are integrated and the absolute magnitude of the gradient is calculated.

$$|\nabla_f| = \sqrt{G_x^2 + G_y^2}$$

Step 6: The absolute magnitude results defined as the slope magnitude image output

Step 7: The pixels values of the slope magnitude images are either too small or too big. In order to increase the image visibility, some appropriate factor is used in small pixel values which increase the scale and in large pixel values which decrease the scale.

D. Un-decimated discrete wavelet Transform (UDWT)

The major variance species for the Un-decimated Discrete Wavelet (UDWT) and standard Wavelet Transform are additive, statistics and independent natures [13]. The typical definition of UDWT is same as DWT, but DWT outputs are being impossible for reduction process. Instead, the low and high pass filters are up-sampling the wavelet by inserting zeros between each and every sample image pixel.The DWT is a very efficient method for acquiring the HH high frequency subband but only demerit is it not translate the invariants. An original signal translation is direct to various wavelet coefficients; This process may affect the given image. To overcome this drawback and acquired the complete analyzed signal information, the UDWT is used.

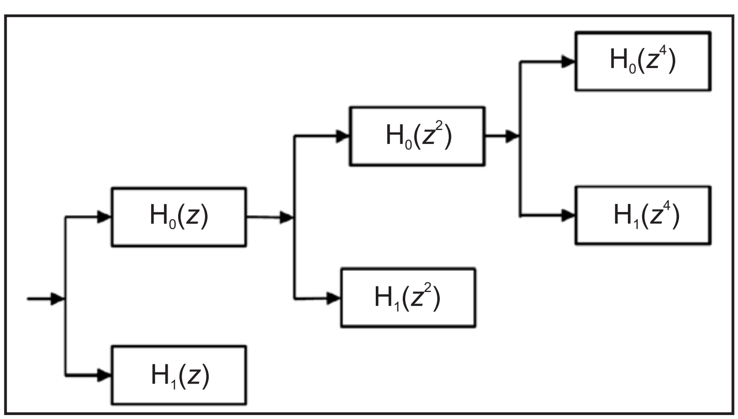

Figure 2: Undecimated Discrete Wavelet Transform

Figure 2 characterized the process of UDWT. In ceramic tiles image, if H_0 (H_1) was a reply of high pass or low pass filters in level one, and then UDWT filters in level "K" have a reply H_0 (H_1) with $2^{k-1} - 1$ zeros which are introduced among each image pixel component.

E. Feature extraction

For features texture extraction process chose the Gray Level Co-Occurrence Matrices (GLCM) matrices and Gabor filters methods. The Gabor filters (GF) is used for localizes in both spatial and space frequency and based on the certain orientation and scale components, the filtered images set is retrieved from the original texture.

An image of I(x, y), defines the subsequent steps for feature extraction.

Feature extraction Algorithm

Step 1: Application of UDWT algorithm is used for decomposition of images into four sub-bands I_{LL}, I_{LH}, I_{HL} and I_{HH} by utilizing wavelet filter coefficients.

Step 2: Comparison with the maximum amount of energy. Calculate the energy for each sub-band.

Step 3: Dividing the ceramic tiles images into non-overlapping windows with size w

Step 4: Calculation of the matrices event pairs of pixels P for distance d = 1 and homogeneity for features vector is utilized.

$$\text{Homogeneity}_{d,\theta} = \sum_i \sum_j \frac{P_{d,\theta}(i, j)}{1 + |i - j|}$$

Step 5: Extraction based on four GLCM metrics such as CON, ENT, IDM and ASM

$$\text{Entropy (ENT)} = \sum_i \sum_j P(i, j) \log P(i, j)$$

$$\text{Contrast (CON)} = \sum_i \sum_j (i - j)^2 \, P(i, j)$$

$$\text{Angular second momentum (ASM)} = \sum_i \sum_j \{P(i, j)\}^2$$

$$\text{Inverse difference momentum (IDM)} = \sum_i \sum_j \frac{1}{1 + (i - j)^2} \, p(i, j)$$

Step 6: Gabor-filtered Fourier transform coefficients is defined as $e_i = \log [1 + P_i]$

Step 7: Gabor filters feature extraction based on following metrics

$$\text{Mean} = \sigma^2 = \sum_{I=0}^{G-1} ip(i)$$

$$\text{Variance} = \sigma^2 = \sum_{I=0}^{G-1} (i - \mu)^2 \, P(i)$$

$$\text{Energy} = \sum_{i,j=0}^{N-1} (p_{i,j})^2$$

$$\text{Skewness} = \mu_3 = \sigma^{-3} \sum_{I=0}^{G-1} (i - \mu)^3 p(i)$$

$$\text{Absolute Value} = \sum_{i=0}^{G-1} \sum_{j=0}^{G-1} |i - j| \, p(i, j)$$

$$\text{Correlation} = \sum_{i,j=0}^{N-1} p_{i,j} \frac{(1 - \mu)(j - \mu)}{\sigma^2}$$

$$\text{Inertia} = \sum_{i=0}^{G-1} \sum_{j=0}^{G-1} (i - j)^2 \, p(i, j)$$

$$\text{Sum Average} = \sum_{i=0}^{2.N_R-2} i\, p_{x+y}(i)$$

$$\text{Dissimilarity} = \sum_{i,j=1}^{S} C_{ij}\, |i-j|$$

$$\text{Auto Correlation} = \frac{MN\sum_{i=1}^{M-p}\sum_{j=1}^{N-q} f(i,j)f(i+p,j+q)}{(M-p)X(N-q)\sum_{i=1}^{M}\sum_{j=1}^{N} f^2(i,j)}$$

$$\text{Kurtosis} = \mu_3 = \sigma^{-4}\sum_{I=0}^{G-1}(i-\mu)^4 p(i) - 3$$

$$\text{Maximum Probability} = TMP = \text{Max}_{i,j}\,(p(i,j))$$

Step 8: Repeat all the steps until sub bands produce feature vector.

F. Artificial Neural Network (ANN)

These extracted features are used to ANN classification processes, it separates the defected tiles or non-defected tiles by using these features.

Typically, this process needs three or more layers: an input variable by using input layer in the classification process, more than one hidden layer, and the output layer with one node per class to be assigned. In the input layer, a number of neurons relied upon the features' vector, and the output layers are depending on the number of defined classes. In this proposed work, a network constructed using a three-layer structure with 20 neurons in the input layer, in hidden layer using 4 neurons and output layer using 2 neurons.

The Artificial Neural Network (ANN) is connected with extracted feature values for automatic defect detection in ceramic tiles. The highly parallel dynamic system of ANN is consisting of several simple units that can execute transformation by their input information. Thus, the learning of the transformation is one the important process in ANN. In ANN, the set of samples is defined as training set.

Table 1

Tiles defects

Defect	*Appearances*
Broken corners and edges	Physical defect on edges and corners
Color grading	Deviations in color shades
Cracks	Long and Thin random physical defects
Dirt	Small random particles on the surface
Drops	Include water and color drops
Lines	Visible direct lines on tile surface,
Pinholes	Very minor holes
Textural problems	Deviations in shape and density of patterns

The input features are defined as x_1 (P), x_2 (P),…, x_n (P), the desired output is $y_{d,1}$ (P), $y_{d,2}$ (P),…. $y_{d,n}$ (P) and the activation function is defined as sigmoid.

Where n denotes number of input neurons j in the hidden layer

$$y_j(P) = \text{sigmoid}\left[\sum_{i=1}^{n} x_i(P).\, w_{ij}(P) - \theta_j\right] \tag{6}$$

$$y_k(P) = \text{sigmoid}\left[\sum_{j=1}^{m} x_{jk}(P).\, w_{jk}(P) - \theta_j\right] \tag{7}$$

Where in output layer neuron *k* is in number of input *m*. θ is threshold levels

$$ek(p) = y_{d,k}(P) - y_k(P) \qquad (8)$$

The given neuron weight is defined as $w_1(p), w_2(p), \ldots, w_n(p)$ and error gradient is defined as $\delta_k(p)$, where $\delta_k(p) = y_k(P).[1 - y_k(P)].e_k(p)$ and the weight correction is $\Delta w_{jk}(P)$ where $\Delta w_{jk}(P) = \alpha.y_j(P).\delta_k(P)$. Different types of ceramic tiles defects are illustrated in table1.

The defect classification phase as follows :

Step 1: Read the ceramic tile image to be analyzed for the defect.

Step 2: Perform all process utilized by training up to feature vector formation of ANN.

Step 3: employ this feature vector to the ANN during in testing stage, and take the yields calculated by the ANN as a defect.

Finally, the ANN approach classifies the defects as broken corners and edges, Cracks, Lines, Pinholes etc.

4. RESULTS AND DISCUSSION

In this proposed work, the tiles image database contains 100 images from 8 types of tiles with various defects, these images used for training and testing phase and 40 % tiles images are defective and 60% tiles images are normal.

A. Metrics

In general, the proposed approach classification system is evaluated in terms of detection rate, accuracy and false alarm rate as in the subsequent formulas

$$\text{Accuracy} = (TP + TN) / (TP + TN + FP + FN) \qquad (9)$$

$$\text{Detection Rate} = (TP)/ (TP + FP) \qquad (10)$$

$$\text{False Alarm Rate} = (FP) / (FP + TN) \qquad (11)$$

$$\text{Specificity} = \frac{TN}{FP + TN} \qquad (12)$$

$$\text{Sensitivity} = \frac{TP}{(TP + TN)} \qquad (13)$$

Evaluation metric as shown in Table 2

Table 2
Evaluation Metrics

Actual \ Predicted	*Normal*	*Attack*
Normal	True negative (TN)	False positive (FP)
Abnormal	False negative (FN)	True positive (TP)

B. Results

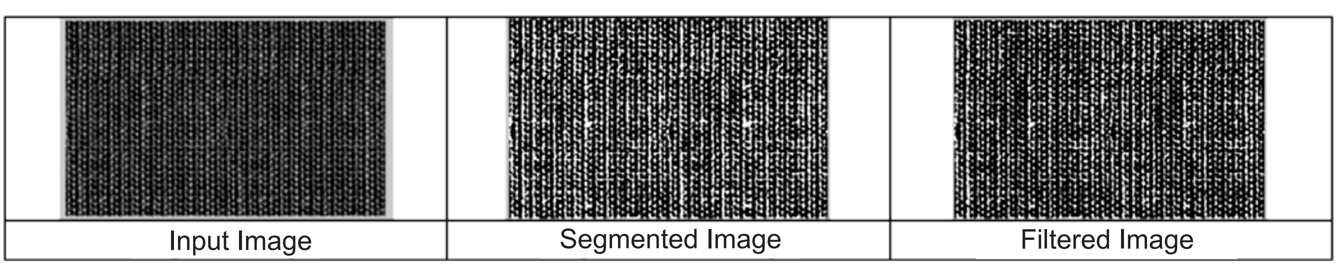

Figure 3: Implemented Tiles Images

Figure 3 shows the sample implemented tiles images which consist of different process images such as the input image, segmented image, filtered image.

Table 3
Classification Efficiency

Defect	*Efficiency*	*Texture Feature*	*Results*	*Color Feature*	*Results*
Blob	99.79	Mean	7.42	Energy	9.50
Scratch	98.69	Variance	7.02	Contrast	1.25
Pitting	97.99	Energy	5.48	Dissimilarity	1.79
Crack	99.56	Smoothness	9.99	Sum Average	1.58
Texture	99.99			Maximum Probability	9.74
Long Crack	99.78			Absolute Value	1.644
Corner	100			Correlation	6.20
Edge	100				

Table 3 and figure 4 results show that the proposed system classification has better efficiency and text and color feature results. The proposed system displays the promising results in different types of ceramic tiles defects. Figure 5 show the proposed work sensitivity results with 83.86 % and figure 6 shows the proposed work specificity results with 99.99 %, these two experimental results shows the promising result in terms of tile defect detection accuracy with 98.44 %.

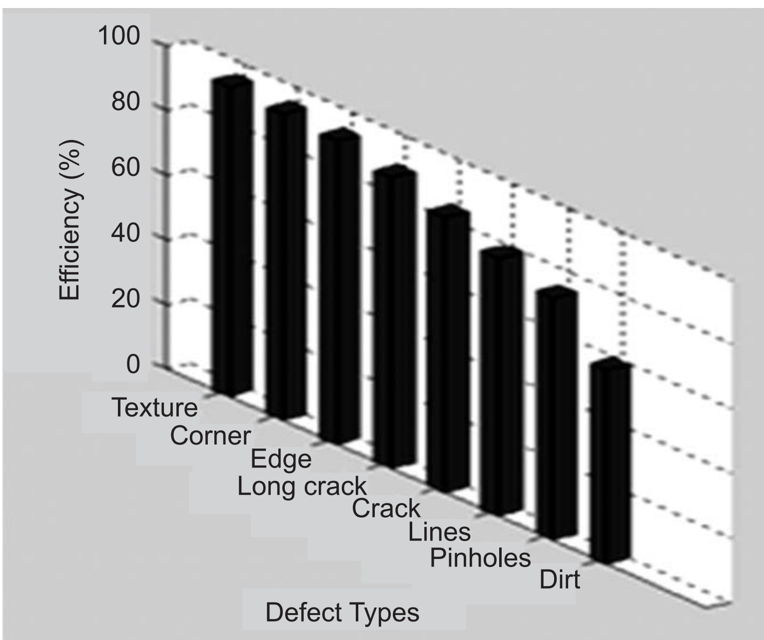

Figure 4 Classification Efficiency

Figure 7 results show that the proposed Un-decimated Discrete Wavelet Transform (UDWT) based feature extraction using GLCM and Gabor filter at various frequency extraction and ANN classification takes half of the time taken by previous UDWT based Gray Level Co-Occurrence Matrices (GLCM) features extraction approach.

Initially, neuron weights are assigned randomly and update the values according to the threshold values at the time of ANN training phase. The updated and initial deviations of the threshold and weight values are shown in figure 8. The weight and updated values are very similar in a particular time. So it minimizes the training and testing time of ANN classification.

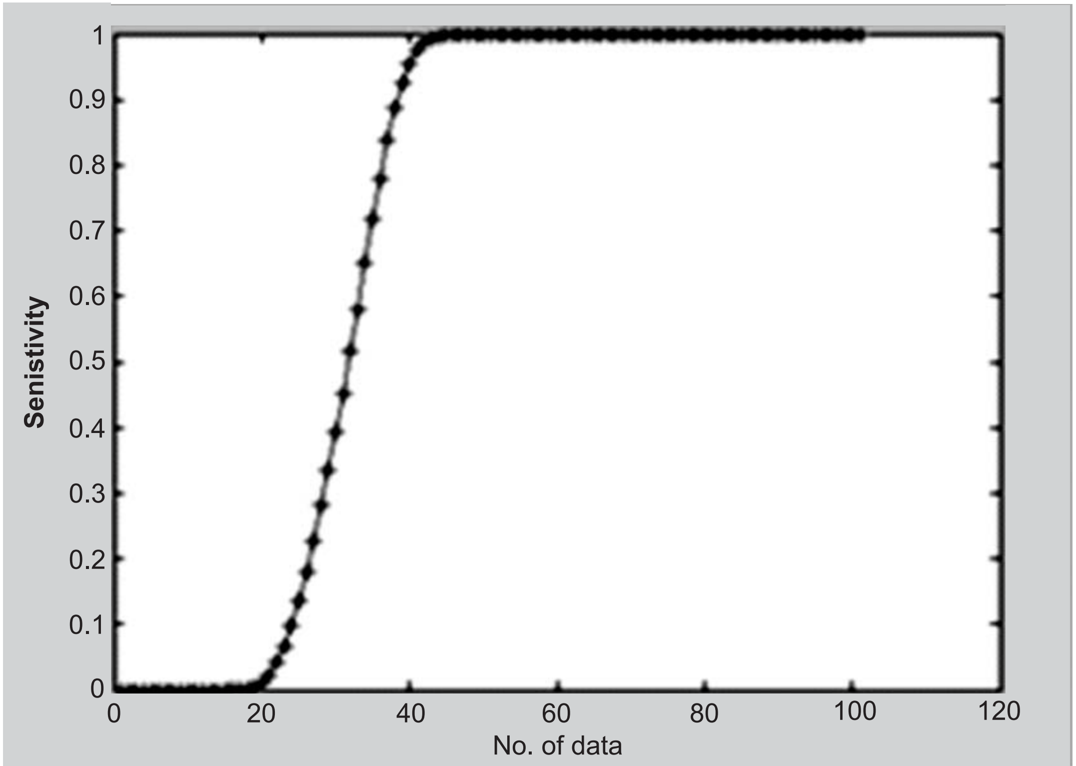

Figure 5: Sensitivity

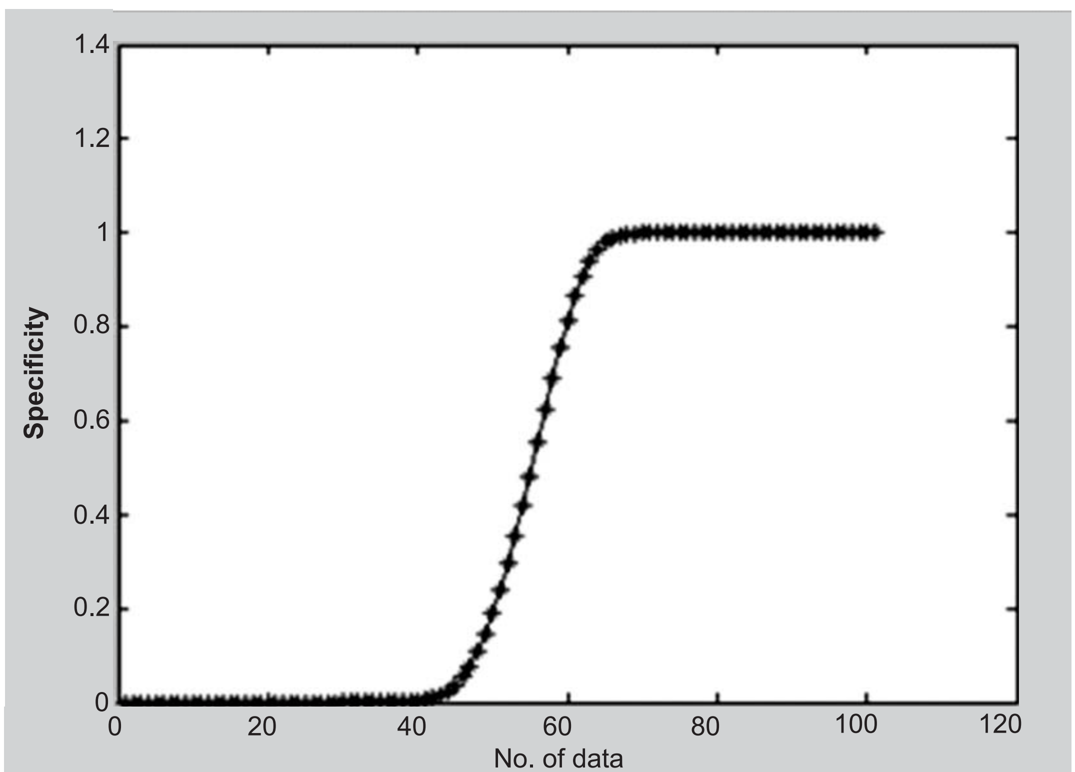

Figure 6: Specificity

5. CONCLUSION

In this paper, un-decimated discrete wavelet Transform (UDWT) is employed to acquire the HH high frequency sub-band ceramic tile image. Then GLCM and Gabor filter is employed in the latter at various frequencies to extract the features and Artificial Neural Network is used for defected tile classification process and By using multiple feature extraction algorithms such as GLCM and Gabor filter, it was found that the quality of correctly matched features could be significantly improved. The experimental results show that the proposed algorithm enhances the detection rate over the classification performance than the previous algorithm and it also reduces the ceramic tiles classification and detection time to half of the previous algorithm and also proposed algorithm can detect the different types of unknown and known features of the ceramic tiles simultaneously.

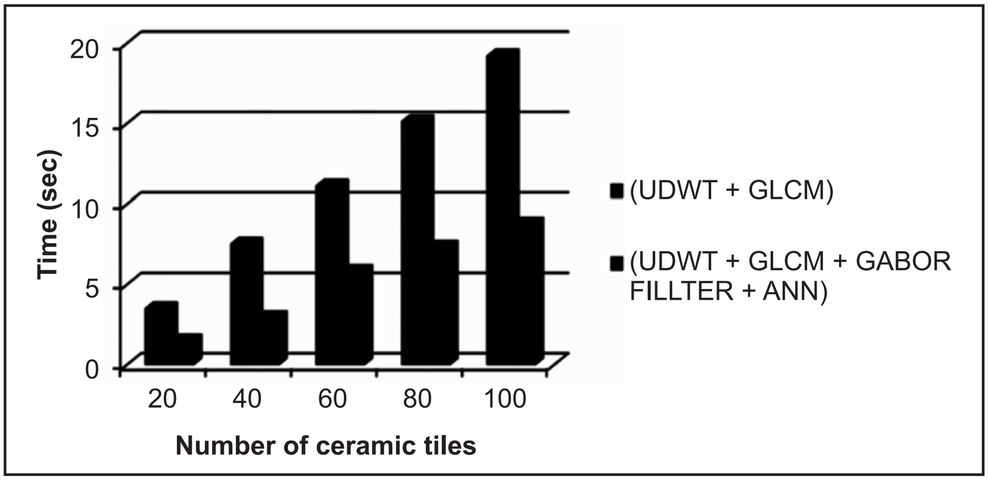

Figure 7: Total Classification Time

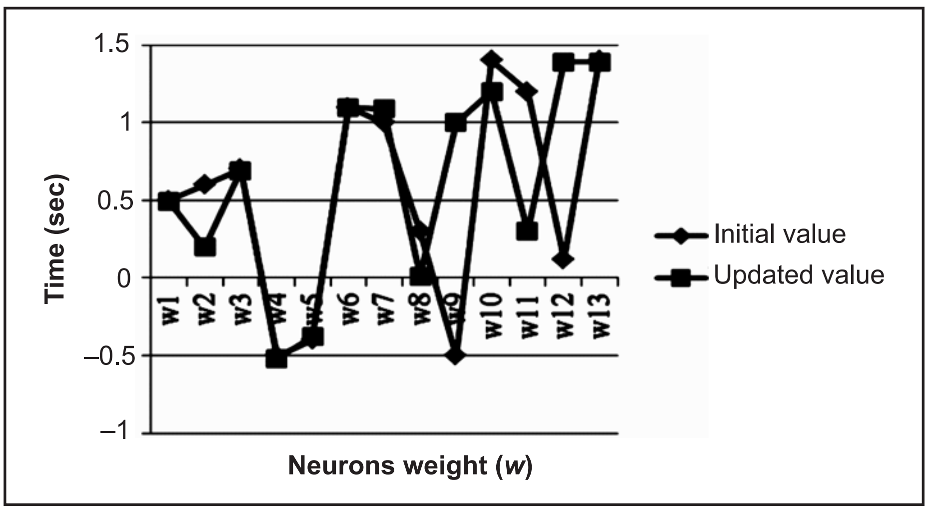

Figure 8: Weight Factors

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