Defect Detection and Analysis using Image Processing

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Abstract- *This paper describes an Image processing-based approach for defect detection and analysis of Magnetic Tile images. The preprocessing of the image involves employing appropriate denoising techniques to obtain the background illumination profile of the image. These preprocessed images are subtracted from the original image to obtain the features of interest for Crack, Blowhole and Fray defects. Here, contour approximation method is used for segmentation of the defect in Cracks and Blowholes whereas Wavelet transforms are applied to the Magnetic Tile images for detection and segmentation of the Fray defect. Classification and Segmentation accuracies have been calculated and shown that the result of this method can be used as an input to deep learning models for further analysis.*

***Key Words-* Crack, Blowhole, Fray, Defect, Edge Detection, Texture Classification, Denoising, Thresholding, Non-Local Means Denoising, Contour Detection, Circularity, Elongation of Contour, Median Filtering, Gabor Filter, Gabor Filter Banks.**

INTRODUCTION

Finding defects in manufactured products is one of the key components in Quality Control and the determination of the longevity of a product. Analyzing these defects helps the manufacturer to filter out the damaged goods to improve the efficiency of the final product thereby maintaining the brand value of the product. It is hence of extreme importance to find and analyze the properties of these defects. A defect detection system can be used to give feedback to the manufacturer pointing to the source of the defect. One such defect is analyzed in this paper, namely the Magnetic Tile defect. Magnetic Tiles are used in various electromechanical devices, such as motors, many modern-day electronic devices such as speakers, and in children's toys. This paper presents an Image Processing based system for defect detection on Magnetic Tiles, namely the Cracks, Blowholes and Frays. The images used for the task of segmentation and classification have been adopted from the work entitled 'Surface Defect Saliency of Magnetic Tile' by Huang et. al [1]. The existing works in defect detection and segmentation employ deep learning algorithms such as YOLO, U-Net, etc. which require labelled and segmented ground truth labels for prediction.

The presented system has been designed for Automatic Labelling of defects and creation of a Dataset which can be fed into complex deep learning segmentation networks such as U-Nets, thereby reducing the valuable man-hours required for creation of dataset for this classification task.

BACKGROUND

Image Denoising

The aim of image denoising is to reduce noise from noisy images while preserving the features of interest. The features of interest are typically high frequency components of the image, such as edges, corners etc. In Spatial domain filtering, a select neighborhood of size K x K is chosen and based on the relationship between the pixels in the neighborhood, a mathematical function calculates the new pixel values in this neighborhood. We have used two such Denoising techniques as given below.

Non-Local Means Denoising

The non-local means algorithm works by replacing the value of a pixel by an average of a neighborhood of other pixels values: small patches centered on the other pixels are compared to the patch centered on the pixel of interest, and the average is performed only for pixels that have patches close to the current patch.

Non - Local Means Denoising Filter given for a noisy image is given by [2]-

$$NLu(p) = 1/C(p) \int f(d(B(p), B(q))\, u(q)\, dq \qquad (1)$$

Where $d(B(p),\, B(q))$ is the Euclidean distance between image patches centered at $p,\, q$ respectively, f is a decreasing function and $C(p)$ is the normalizing factor.

Median Blurring

Median Filter is a non-linear filter, used to remove salt and pepper noise from images. The median filtering of an image is carried out by sliding a window over the pixels in an image and replacing the center pixel of the window with the median value of pixels in the neighborhood.

An example of a 3 x 3 median kernel on a 4 x 4 image padded with zeros is given as follows:

0	0	0	0	0	0
0	100	150	50	190	0
0	140	130	50	100	0
0	170	140	65	150	0
0	120	190	55	160	0
0	0	0	0	0	0

Fig 1- 6x6 Input Image, kernel = 3x3

0	50	50	0
130	130	130	50
130	130	130	55
0	65	65	0

Fig 2- Output after Median Blurring

Gabor Filter

The Gabor filter which was named after Dennis Gabor is a linear filter which is used for texture analysis, edge detection, and typically for extracting desired features with specified orientation and frequency. The Gabor filter analyses a specific region for frequency components in specific directions. It is a bandpass filter in the sense that it allows certain band of frequencies corresponding to features of interest while rejecting the rest.

The Gabor Wavelet filter equation given by [2] is as follows

$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = exp(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}) exp(i (2\pi \frac{x'}{\lambda} + \psi)) \quad (2)$$

Here,
$$x' = x \cos\theta + y \sin\theta$$
$$y' = -x \sin\theta + y \cos\theta$$
$$(3)$$

The filter consists of a real and an imaginary component which represent orthogonal directions. In the above equation, g denotes the Gabor filter, λ denotes the wavelength of the sinusoid, θ is the orientation of the normal to the parallel stripes of Gabor function, ψ is the phase offset of the sinusoid function, σ is the standard deviation of the Gaussian envelope and γ is the spatial aspect ratio of the filter.

Canny Edge Detection Algorithm

The Canny Edge detection Algorithm is an infamous edge detection algorithm developed by John F Canny [4]. It's a multistage edge detection algorithm where intensity gradient of a denoised image is calculated and a non-maximum suppression is applied to the intensity gradient to remove unwanted pixels which might not constitute an edge. Every pixel is checked for satisfying the conditions of local maxima in a neighborhood and in the direction of the intensity gradient given as-

$$\text{Edge gradient} = G = \sqrt{G_x^2 + G_y^2} \quad (4)$$

$$\text{Direction (Angle)} = \theta = \tan^{-1}\frac{G_y}{G_x} \quad (5)$$

Finally, Hysteresis thresholding is performed using two values, a minimum intensity gradient value and maximum intensity gradient value. The edge pixels which are above the max gradient value are sure edges and the ones below min gradient value are discarded. The edges lying between the two thresholds are valid edge pixels if they are connected to the sure edges.

Convolution of Images

Convolution is a mathematical multiplicative operation carried out on two signals of varying sizes but same dimensionality to output a third signal of same dimensionality. It is generally used for the purpose of filtering and feature detection in images and signals. The 2-D discrete convolution between two images given by *x(m, n)* and *h(m, n)* is given by

$$y(m, n) = \sum_{k1=0}^{m} \sum_{k2=0}^{n} x(k1, k2) h(m - k1, n - k2) \quad (6)$$

Thresholding of Images

For an input gray image *g(x,y)*, the thresholded image *f(x,y)* can be defined as follows-

$$g(x, y) = \begin{cases} 1, & for \ f(x,y) > T \\ 0, & for \ f(x,y) \le T \end{cases} \quad (7)$$

where T is the threshold gray level intensity.

METHODOLOGY

The proposed method for the detection and classification of defects using Image Processing is two-fold, namely, preprocessing and segmentation of the image to extract the desired features such as Cracks, Blowholes and Frays of Magnetic Tiles.

The Preprocessing Stage.

The input images were converted from the BGR colorspace to Grayscale colorspace for processing. Two methods were applied to offset the distortions produced by varying degrees of luminance in the images.

Firstly, the gray level values of the images with high luminance were truncated to lie between the gray levels of 0-120. This was done to reduce the high contrast present in the image between shadows and glares.

Secondly, the background illumination profile of the image was obtained by the effect of blurring. For small defects such as cracks and blowholes, this method effectively blurred the desired features beyond recognition thus retaining the illumination profile of the background. The denoising algorithm chosen for blurring is the python implementation of the Non-Local Means Denoising Algorithm given by equation (1) and as explained by Baudes *et. al.*, [3] and further by using Median Blur Filter where the pixels in a certain neighborhood are replaced by the median value of the neighborhood. The resulting image was subtracted from the denoised image to obtain the illumination invariant output with crack and blowhole defects. This image is fed into the image segmentation pipeline to segment the defects.

Image Segmentation

Contour Detection and Classification-

The cracks on Magnetic Tile Surfaces taken from the dataset [1] were preprocessed. Canny edge algorithm [3] was used to detect the edges corresponding to the crack. Furthermore, morphological techniques such as dilation, erosion and closing were applied to connect the disjointed crack components. Contour detection algorithm was then applied to the dilated image and filtered by parameters such as contour area and perimeters to extract the contour and its properties.

The classification of the contour into a crack or a blowhole was carried out by calculation of three parameters- circularity, elongation of a contour and the area of the contour.

The circularity of a contour was calculated using the following equation-

$$Circularity = c = \frac{4.\pi.area}{perimeter^2}$$

Where a circle has the circularity=1 and a straight line has circularity=0

Blowholes are typically more circular and have smaller total area than the crack defect whereas elongation of cracks is greater than blowholes. And therefore, appropriate threshold values were chosen for differentiating between cracks and blowholes. For the task of classification of the entire image for labelling purposes, the contours were sorted into categories- weak cracks, strong cracks, weak blowholes and strong blowholes depending on their areas and circularities of the contours. An image is labelled as a crack defect image if the image consists of predominantly weak and strong cracks. An image is labelled as a blowhole defect image if it there exist a higher number of strong and weak blowholes than cracks in an image.

Fray Detection and Segmentation

For Fray Detection, the input image was first denoised using non-local denoising and median filtering techniques. And since Frays have rather large areas and have distinctively separate gray levels, Gabor Filters were used, given by Equation (2). This image was further thresholded to obtain appropriate features above a certain gray level intensity (7). Subsequently after tuning the parameters associated with the filter - $\lambda, \theta, \psi, \sigma, \gamma$, we obtained numerous Gabor Filters for various orientations and feature sizes. The parameter values were chosen according to [4] as these parameter constraints give the best results for feature detection. The resultant filters were added and convoluted with the original image according to Equation (6). And yet some filters were used to remove long streaks of noise present in the image.

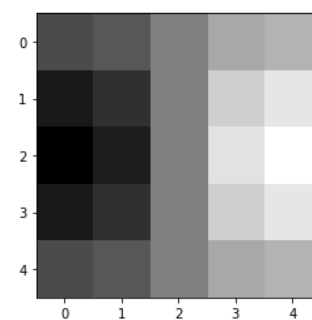Some examples of the Gabor filters used were as follows-

Fig 3- 5 x 5 kernel
Θ= 0°, σ= 3.0, λ= 9.0, γ=0.3, φ=0°
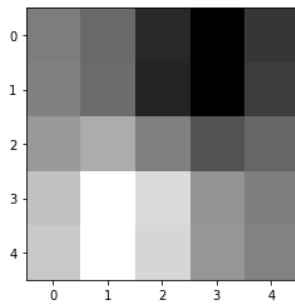
Fig 4- 5 x 5 Kernel,
Θ= 120°, σ= 3.0, λ= 8.0, γ=0.3, ϕ=0°

Gabor filter was primarily selected due to irregular shape, the vastly non uniform size of the defect, and the varying contrast between the foreground and the background pixels. The output of the convolution was then further processed to obtain the segmented defect using Active contour drawing and flood filling algorithms.
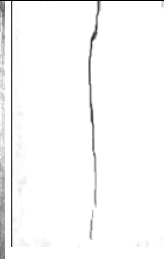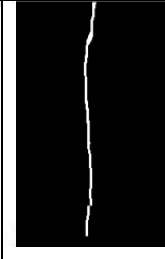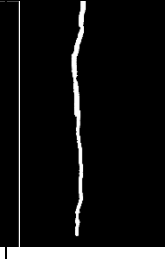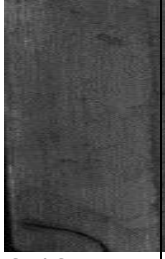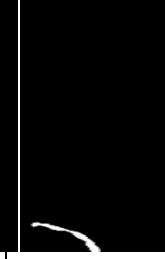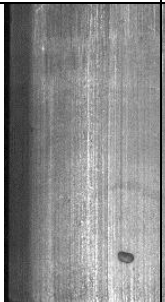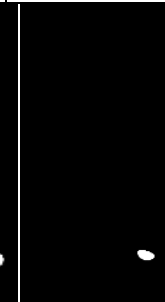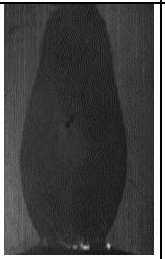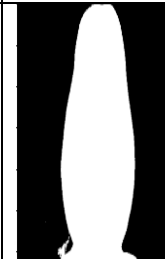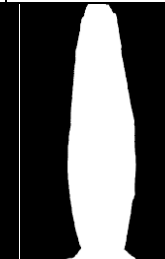
RESULTS AND DISCUSSION

The Table.1 below lists the number of images processed, correctly produced outputs for cracks and blowholes, and describes output statistics of the processed data.

Table 1- Output Statistics of Processed Images

Total number of Images Processed (Cracks and Blowholes)	169
Number of Images classified correctly	161
Total number of crack defect images	57
Number of cracks correctly classified and detected	56
Total number of blowhole defect Images	115
Number of blowholes correctly detected and classified	105
% Accuracy for detection of blowholes and cracks	95.22%

Table 2: Outputs of segmentation of defects using Image Processing, comparison with Ground Truth Images

Input defect Image	Preprocessed Image	Output detected defect	Ground truth
CRACK			
CRACK			
BLOW-HOLE			
FRAY			

The Accuracy of defect localization when compared with ground truth images obtained for the Fray Images is approximately 78%. The Accuracy of defect localization obtained for the batches of Crack and blowhole defects was approximately 91.5%. The Accuracy metric was calculated using the Confusion Matrix given as follows:

Therefore, Accuracy has been calculated as:

$$Accuracy = \frac{Number\ of\ TP + TN}{Number\ of\ TP + TN + FP + FN} \times 100$$

TRUE CLASS

	Positive	Negative
Positive	True Positive (TP)	False Positive (FP)
Negative	False Negative (FN)	True Negative (TN)

PREDICTED CLASS

Fig 5- Confusion Matrix

CONCLUSION-

On the basis of the image analysis carried out, we can conclude that Automatic Labelling of dataset of Magnetic Tile defects with high degree of variance in luminance, noise and defect variations can be performed by Image Processing techniques using Edge algorithms, and Wavelet transforms only after applying the necessary denoising to the image. The execution time for this system is approximately 0.3s on an i5 7th Generation CPU. While this time is not employable for real time applications, it can serve to be an effective feeder for the deep learning pipeline of an Automatic Defect Detection System.

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