Enhanced Image Thresholding Algorithm and Defect Detection for Plain Ceramic Tiles' Surface

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Abstract— The processes of Image retrieval and image classification are playing one of the important roles in field of image processing and pattern recognition, these days. With the advancements in technology and modernization, real world and real time image data has shown an enormous amount of increase. To store and process this data, powerful image retrieval tools are required. Therefore developing such kind of powerful tool is a major task of many industries to deploy those tools in automatic machine/industrial vision systems and applications. This article focuses on the field of detecting and analyzing surface defects using image processing techniques that is applicable to 'Ceramic Tile Industry'. The work carried out in this report summarizes about various defects found in plain ceramic tiles; their classification and statistical characterization and thereby standardizing the tiles according to their quality.

The major tasks in such a process includes image capturing, conversion to gray level image, thresholding, equalization and statistical measurements. The defects may be in form of pin-holes, spots/bumps, cracks etc. For deciding the threshold, an improvement over 'Otsu Algorithm' is being used which provide a significant reduction in error and improvement in results. The statistical characterization involves parameters like Centre of Gravity, Max/Min Radii in each quadrant, Figure Aspect, perimeter, Area, Axes Intercepts etc.

Keywords—*Defect Identification, Thresholding, Cracks, Spots, Holes.*

I. INTRODUCTION

Computer vision is a novel technology for acquiring and analyzing an image of a real scene by computers and other devices in order to obtain information, or to control processes. The core technique in computer vision is always related to image processing, which can lead to segmentation of objects of interest within images and thus finally to qualification and then classification of images.

Image processing is one of the mostly increasing areas now-a-days. The analog imaging is switched to the digital system. Digital image processing is used to extract various features from images by computers automatically. One of the most important operations on digital image is to identify and classify various kinds of defects. Thus to detect the defects from any image some methods are established and placed. At the first level, some techniques are available which deal directly with the raw, possibly noisy pixel values, with de-noising and edge detection. In the second level there are algorithms which utilize low level results, such as segmentation and edge linking. At the final level those methods which attempt to extract semantic meaning from the information provided by the first level. In ceramic tiles industry sector sometimes checking is needed for the ceramic tiles if they are able to serve customer needs, i.e. to find defected tiles. So it is an important task to categorize the ceramic tiles after production based on surface defects. The manual method of defects inspection is labour intensive, slow and subjective [5].

In every industry, the detection of defects in the surface texture is an important part of many quality control applications. The detection of features and classification based on it in a digital image is the key requirement in quality control systems in production. Conventionally, humans were engaged to detect defects in the surfaces and they used to present report sheets based on their assessment. But, this process is a time consuming and expensive one. An inspection system to replace human inspectors should be capable of detecting flaws such as scratches, stains, (textural defects) and dents, cracks, blow holes (structural defects) occurring in various shapes and sizes. The problems may arise by these types of defects and reduces the production chain. The products which are defective is not suitable in the industries and they must be rejected during the production process. This gave way to numerous automated techniques for the detection of defects [7].

The presented work aims to create a visual system that is capable of detecting the surface defects for the fired ceramic tiles which will ensure that products are defect-free and thus can be classified according to their quality. Classifying process must be carried out objectively, effectively and repeatedly and that too with sufficient rapidness and incurring low costs. This process must be able to adapt itself autonomously to the changes in materials. The techniques used can be applied for Cracks (Long Cracks & Short Cracks), Pin-holes, Blobs and Spot detectors algorithms for plain tiles.

The organization of this paper is as follows. In the upcoming section basics of Thresholding, Otsu Thresholding and Karimi's Method [2] is discussed in detailed. Analyzing that both the methods yields the same results for thresholding purpose, a new and efficient method to find the optimum threshold based on entropy is then presented. In section III the proposed method is used on some test images, evaluated and compared with the existing *(Otsu's and Karimi's)* methods. Finally the conclusion section IV provides a summary of the complete process and results.

II. THRESHOLDING FOR A IMAGE

A. Introduction

During the thresholding process, individual pixels in an image are marked as "object" pixels if their value is greater than some threshold value and as "background" pixels otherwise. This convention is known as threshold above. Variants include threshold below, which is opposite of threshold above; threshold inside, where a pixel is labeled "object" if its value is between two thresholds; and threshold outside, which is the opposite of threshold inside. Typically, an object pixel is given a value of "1" while a background pixel is given a value of "0." Finally, a binary image is created by coloring each pixel white or black, depending on a pixel's label's [1].

The output of the thresholding operation is a binary image whose one state will indicate the foreground objects, that is, printed text, a legend, a target, defective part of a material, etc., while the complementary state will correspond to the background. Depending on the application, the foreground can be represented by gray-level 0, that is, black as for text, and the background by the highest luminance for document paper, that is 255 in 8-bit images, or conversely the foreground by white and the background by black

B. Otsu's Method

If the number of pixels which have gray levels equal to i, is named n_i and n is the number of all pixels, the occurrence probability of i_{th} level is as follows:

$$p_i = \frac{n_i}{n}$$

Average gray level of image can be calculated using following equation:

$$\mu_T = \sum_{i=0}^{L-1} i p_i$$

where L is total number of gray levels in image. There are two classes assumed:Background (*0* to *t-1*) C_b and Foreground (*t* to *L-1*) C_f where *t* is any intermediate level *(assumed as threshold*)

Weight/appearance probability of each pixel in each class can be given by using following equations

$$\omega_b(t) = \sum_{i=0}^{t-1} p_i = \sum_{i=0}^{t-1} n_i/n \quad , \quad \omega_f(t) = \sum_{i=t}^{L-1} p_i = \sum_{i=t}^{L-1} n_i/n$$

where subscripts '*b*' and '*f*' are used to depict background and foreground terms. Normalized average within class for two classes are and are described as: [2],[20]

$$\mu_b(t) = \sum_{i=0}^{t-1} i p_i \Big/ \omega_b(t) = \sum_{i=0}^{t-1} i n_i / n_b$$

and

$$\mu_f(t) = \sum_{i=t}^{L-1} i p_i \Big/ \omega_f(t) = \sum_{i=t}^{L-1} i n_i / n_f$$

where n_b and n_f are total number of pixels in background and foreground respectively.

Between Class Variance and Within Class Variance are given by:

$$\sigma_{bcv}^2 = \omega_b(t)[\mu_b(t) - \mu_T]^2 + \omega_f(t)[\mu_f(t) - \mu_T]^2$$

and

$$\sigma_{wcv}^2 = \omega_b(t)\sigma_b^2 + \omega_f(t)\sigma_f^2$$

where σ_b^2 and σ_f^2 are individual class variance of background and foreground variances and given by

$$\sigma_b^2 = \sum_{i=0}^{t-1} (i - \mu_b(t))^2 p_i \Big/ \omega_b(t)$$

and

$$\sigma_f^2 = \sum_{i=t}^{L-1} (i - \mu_f(t))^2 p_i \Big/ \omega_f(t)$$

These values are calculated for each t *(0 to L-1)* for a gray level image and then that 't' is selected as threshold for which between class variance is maximum or within class variance is minimum.

Thus optimal threshold t* is given as:

$$t^* = ArgMax\{\sigma_{bcv}^2(t)\} \quad (1)$$

or

$$t^* = ArgMin\{\sigma_{wcv}^2(t)\} \quad (2)$$

C. Karimi's Method

Karimi et.al [2] in 2013 proposed a method to find a threshold given by:

$$t^* = ArgMax\{\sigma_{bcv}^2(t) - \sigma_{wcv}^2(t)\} \quad (3)$$

where symbols have meanings defined in above sub article B

However mathematical calculations and coding results show that equations (1), (2) *(Otsu equations)* and equation (3) yields the same value of threshold for any given image.

D. Proposed Thresholding Method- Entropy Based

The procedure commences by first creating a histogram, partitioned into L parts. This method of finding the optimal threshold *t** is based on dividing the image in two sections for all values of t, when t is varied from 0 to 255. The two sections are called background section (B) and foreground section (F). The histogram of section B is from *0 to t-1* and the rest *(t to L-1)* is in section F, where *L* is total number of gray levels in image and *t* is any intermediate level (assumed as threshold). The probability to weight ratio is calculated for each t in each section to get new set of probabilities.

Then Shanon Theorem of finding entropy is applied on each section to get two entropies namely Background Entropy $H_b(t)$ and Foreground Entropy $H_f(t)$ for each t.

The set of new probability distributions are then obtained as:

Section B:

$$\frac{p_0}{\omega_b(t)}, \quad \frac{p_1}{\omega_b(t)}, \quad \frac{p_2}{\omega_b(t)} \cdots\cdots\cdots\cdots \frac{p_{t-1}}{\omega_b(t)}$$

Section F:

$$\frac{p_t}{\omega_f(t)}, \quad \frac{p_{t+1}}{\omega_f(t)}, \quad \frac{p_{t+2}}{\omega_f(t)} \cdots\cdots\cdots\cdots \frac{p_{L-1}}{\omega_f(t)}$$

Background Section (Section B) Analysis:

$$H_b(t) = -\sum_{i=0}^{t-1} \frac{p_i}{\omega_b(t)} \ln \frac{p_i}{\omega_b(t)}$$

$$= -\sum_{i=0}^{t-1} \frac{p_i}{\omega_b(t)} \ln p_i + \sum_{i=0}^{t-1} \frac{p_i}{\omega_b(t)} \ln \omega_b(t)$$

$$H_b(t) = \frac{H_b}{\omega_b(t)} + \ln \omega_b(t)$$

where

$$H_b = -\sum_{i=0}^{t-1} p_i \ln p_i$$

Foreground Section (Section F) Analysis:

$$H_f(t) = -\sum_{i=t}^{L-1} \frac{p_i}{\omega_f(t)} \ln \frac{p_i}{\omega_f(t)}$$

$$= -\sum_{i=t}^{L-1} \frac{p_i}{1-\omega_b(t)} \ln \frac{p_i}{1-\omega_b(t)}$$

$$or \qquad H_f(t) = \frac{H_f}{1-\omega_b(t)} + \ln(1-\omega_b(t))$$

where

$$H_f = -\sum_{i=t}^{L-1} p_i \ln p_i$$

Defining $H(t)$ as sum of above two entropies

$$H(t) = H_b(t) + H_f(t)$$

The optimal threshold value is then defined as the location in the histogram where $H(t)$ is maximum. This results in simple but elegant approach for determining the threshold value.

$$t^* = ArgMax\{H(t)\}$$

III. Feature Extraction and Defects

All features are centre of mass oriented. Therefore, very firstly, the centre of mass is computed by using the first order moments as follows: [5]

$$G_x = (1/N) \sum X_i$$

$$G_y = (1/N) \sum Y_i$$

where (X_i, Y_i) are the coordinates of the pixels on object (defect in the proposed case) in image and 'N' is the total no. pixels on the object.

The radii are computed by using the following formula:

$$R = \sqrt{\{(X_c - G_x)^2 + (Y_c - G_y)^2\}}$$

where (X_c, Y_c) and (G_x, G_y) are the contour and centre of mass coordinates respectively.

$$FA = (X_1 + X_2) / (Y_1 + Y_2)$$

where X_1, X_2, Y_1, Y_2 are the intercepts on +ve and –ve X and Y axes respectively.

After computation of all radii, maximum and minimum radii are sorted from the radii array as computed above in all four quadrants. This exercise gives the estimate of the defect shape i.e. crack, hole or spot. A hole or a circular defect is identified by the fact that all its maximum and minimum radii are nearly equal. In-fact the intercepts formed in this defect are nothing but radii of the hole. So figure aspect ratio comes out to be approximately unity. Also all radii are divided by mean radius to get normalized radii which will again lie somewhere near to unity. A crack is normally a linear defect which may occur horizontally or vertically. In almost horizontal cracks, intercepts on X axis are longer than intercepts on Y axis. So figure aspect ratio comes out to be large. However in almost vertical cracks, intercepts on Y axis are longer than intercepts on X axis. So figure aspect ratio comes out to be very small.

Spots are normally any defect other than crack and hole. They can be of any irregular and random shape. Presence of unwanted materials also comes under the category of spot. Defects having the parameters other than those defined for defect detection in cases of cracks or holes have been considered as spots. More precisely bumps and holes like defects are identified by using the edge detection techniques.

In addition, area and perimeter of the segmented defect is also calculated to represent it quantitatively.

Peak signal-to-noise ratio, often abbreviated PSNR, is a term for the ratio between the maximum possible power of a signal and the power of interfering/distorting noise that affects the quality of its representation. PSNR is most easily defined via the mean squared error (MSE). Given a noise-free $m \times n$ monochrome image I and its any other approximation A, MSE is defined as:

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

The PSNR is defined as:

$$PSNR = 10 \log_{10}\left(\frac{MAX_F^2}{MSE}\right)$$

IV. EXPERIMENTAL RESULTS

This section is divided in two sub sections each having threshold and analysis results. First sub section has results for defective images while other for defectless image.

A.Defective Images

Following figure shows the input images which are named as Test Image 1, Test Image 2 and Test Image 3 and each is suffering from a defect which are used to find the results.

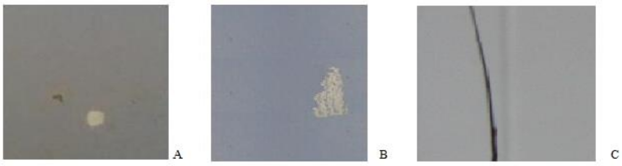

Fig 1: Test Images (Defective)
A) Test Image 1 B) Test Image 2 C) Test Image 3

The following table show the results of threshold, MSE and PSNR values using Existing Methods and proposed Method. This table also list the entropy value. This table is followed by the three images which clearly show the output binary (black and white) images of two algorithms.

TABLE I. RESULTS FOR DEFECTIVE IMAGES

Images		Test Image 1	Test Image 2	Test Image 3
Using Existing Method	**Normalized Threshold**	0.486	0.592	0.467
	Threshold	124	151	119
	MSE	11.089	19.447	92.323
	PSNR	85.812	83.372	76.608
Using Presented Method	**Normalized Threshold**	0.527	0.592	0.558
	Threshold	134.472	145.429	142.441
	MSE	11.09	18.685	40.138
	PSNR	85.812	83.546	80.226
Entropy		0.991	0.592	0.152

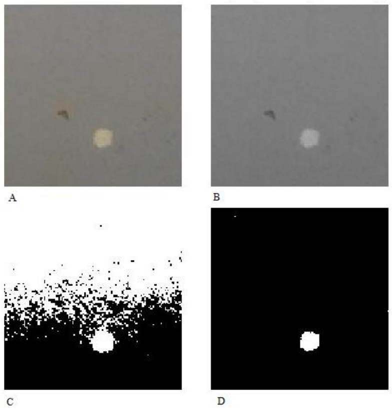

Fig 2: Test Image 1 Results
A) Original Image B) Gray Scale Image
C) Image thresholded with Existing Algorithm
D) Image thresholded with presented algorithm

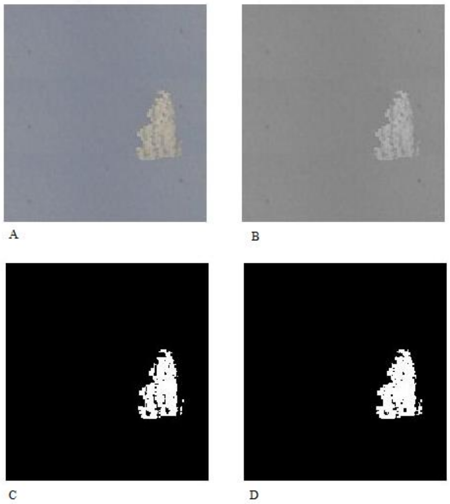

Fig 3: Test Image 2 Results
A) Original Image B) Gray Scale Image
C) Image thresholded with Existing Algorithm
D) Image thresholded with presented algorithm

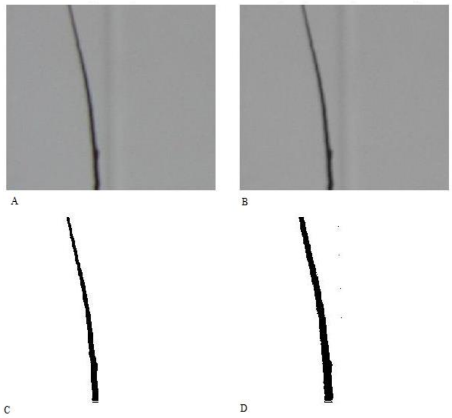

Fig 4: Test Image 3 Results
A) Original Image B) Gray Scale Image
C) Image thresholded with Existing Algorithm
D) Image thresholded with presented algorithm

B.Defectless Image

The following figure is a picture of white plain defectless tile. The threshold, MSE and PSNR results; and binary image output using two algorithms are shown in table II and figure 5.

Fig 5 : Test Image 4 (Defectless)

TABLE II. RESULTS FOR DEFECTLESS IMAGE

Images		Test Image 4
Using Existing Method	**Normalized Threshold**	0.67
	Threshold	171
	MSE	68.718
	PSNR	77.89
Using Presented Method	**Normalized Threshold**	0.609
	Threshold	155.39
	MSE	16.782
	PSNR	84.013
Entropy		0.985

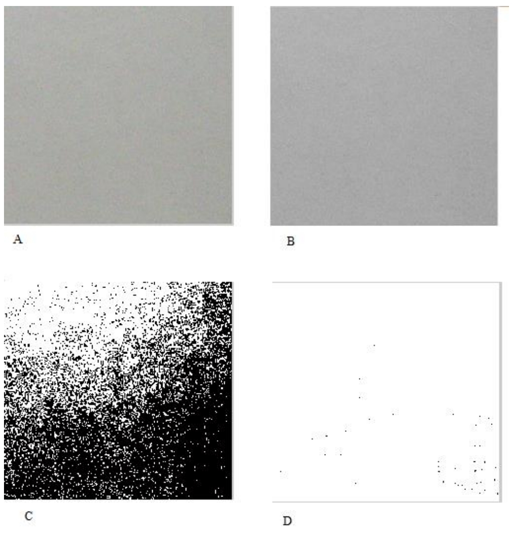

Fig 6: Test Image 1 Results
A) Original Image B) Gray Scale Image
C) Image thresholded with Existing Algorithm
D) Image thresholded with presented algorithm

IV. CONCLUSIONS

With the complete process - proposed algorithms, existing algorithms and result analysis, it can be concluded that the proposed algorithm works better than the existing ones. The threshold results as well as MSE/PSNR results have been enhanced, when applied to plain ceramic tiles. It can easily be observed that entropy based thresholding yields comparatively much better results than Otsu's and Karimi's algorithm. Due to this binary image quality also improves and hence PSNR also improves.

From industrial point of view, the tile's surface defects identification can be automated by installing a camera on top of the production line over the conveyor belt, where the tiles arrive at certain regular interval. The camera along with the image acquisition and surface defects identification can be interfaced with the PC to produce the results based on set criteria. More quality determining parameters can be identified and incorporated into the algorithm for better quality production of tiles. A report indicating the tile's surface may also be generated for the lot of production. And a statistical analysis can also be made regarding a particular trend obtained in the results. The analysis will give the manufacturer an idea about the degree of contribution of an intermediate stage of the production line towards the quality deterioration.

The image processing described in the presented thesis work is supposed to be used for visual quality control in ceramic tile production. The tile's surface quality depends on the surface defects. The described diagnostic algorithm is presented to detect surface failures on plain white and colored ceramic tiles. The tiles are scanned and the digital images are preprocessed and classified using the discussed algorithm. The algorithm is evaluated experimentally using the real tile images (defective and defectless) as well as self made images (defective). The results obtained were satisfactory considering the fact that the images were captured under the normal conditions.

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