Visual Diagnostics Based on Image Wavelet Transform

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Keywords

Diagnostics, industrial applications, new devices, software, system engineering.

Abstract

The image processing described in this paper is used for visual quality control in ceramic tile production. The tiles surface quality is described by the surface defects. The described image processing is based on the discrete wavelet transform method. The diagnostic algorithm is described. It is based on comparing of the wavelet coefficients of the original image without surface defects and the real images of ceramic tiles. The method is verified by using the artificial defects on the image and sensitivity testing on failure contrast and size is done. The algorithm is evaluated experimentaly using the real tile images. The analysis of the detection capabilities and sensitivity expressed in nondetected failures and false proclaimed defect is done also. Optimal connection between the segment size and DSL for each type of surface failure could be used to make efficient system for quality control and failure classification in automated production process.

Introduction

The tiles surface quality is described by the surface defects and the intentional effects such as cracs, crazing, dry spots, pin hole, glaze devitrification, blister, etc. On-line testing of the surface defects is done at the tile factory by the visual testing performed by workers. This way of testing is liable to mistakes produced by human errors and subjectivity. Therefore the visual quality testing should be done more objectively by machine vision [1]. The image processing methods are developed for this purpose. Using the singular value decomposition (SVD) of the matrix of variations of the original image makes the image comparison duration shorter. The number of computer operations decreases by using SVD approximation by a lower rank matrix. But the too low rank of the matrix could yield bad comparison results [2]. So we tried to find the better method which is described in this paper.

Discrete Wavelet Transform

The perception of a varying illuminance surface by the human visual system (HVS) incorporates a large number of different mechanisms. In the first stage the HVS has the properties of the spatial-frequency filter. Furthemore, there is an adaptation of the visual analysis to the stimulus dimensions, [3]. Marcelja has provided a mathematical description using the Gabor transform. Gabor transform introduces a spatial window in the Fourier integral, and on that way achieves the spatial adaptation of the Gabor basis functions. But it is not possible to define a priori a resolution for the analysed images.

In the opposition to a window Fourier transform, that has a fixed resolution in the spatial and frequency domains, the wavelet transform provides the multiresolution analysis. The wavelets are defined by a function ψ, which produces the basis functions $\psi_{j,k}$ in the different scales *j* and position *k* by dilatation and translation:

$$\psi_{j,k}(t) = 2^{j/2} \cdot \psi(2^j t - k) \qquad (1)$$

If *j* decreases the resolution decreases in spatial domain and increases in frequency domain. The functions $\psi_{j,k}$ can be orthonormal set of basis function, so that every function in $L_2(\bullet\ )$ can be expanded as a combination of $\psi_{j,k}$:

$$f = \sum_{j,k \in Z} \left\langle f, \psi_{j,k} \right\rangle \cdot \psi_{j,k} \qquad (2)$$

$$x_{j,k} = \left\langle f, \psi_{j,k} \right\rangle \qquad (3)$$

where $\langle f,\psi_{j,k} \rangle$ denotes the scalar product of the functions *f* and $\psi_{j,k,}$ and that gives wavelet coefficients $x_{j,k}$ of the function *f* at the resolution *j*.

The discrete wavelet transform -DWT of an image may be represented [4] as a filtering with a four-channel perfect reconstruction analysis/syntesis filterbank. Lowpass filter H and highpass filter G are applied in the two dimensions: horizontal and vertical, and the downsampling operation is applied to the both directions. The resulting four transform components – the frequency subbands, consist of the all possible combinations of high- and low-pass filtering in two dimensions, so called the orientations. The lowest frequency subband $X_{A,1}$ contains the wavelet coefficients of an image approximation at the lower resolution. Another three subbands: $X_{V,1}$ -vertical, $X_{H,1}$ – horizontal and $X_{D,1}$ – diagonal, contain the wavelet coefficients of the details in the three orientations. In the often used piramidal decomposition schema only the lowest subband is filtered (decomposed) further, as it is presented on Fig. 1. The higher decomposition levels produce the lower frequency subbands in this diagram.

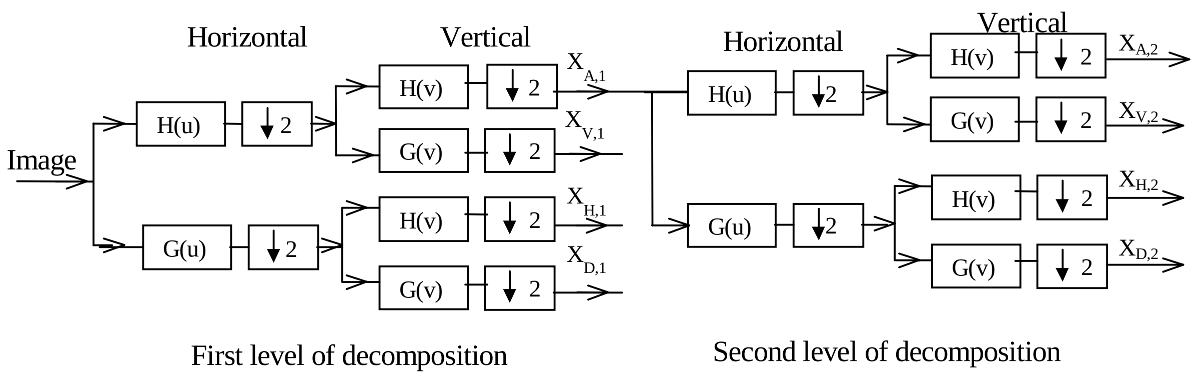

Fig.1: Two levels of a DWT of an image decomposition.

The good spatial localization is achieved in this way for the higher frequency components and the good frequency localization is achieved for low frequency components of an image. The piramidal decomposition algorithm for DWT is a fast algorithm and it can be used for the real-time image processing.

The local contrast of an image is often more informative than the light intensity values. The wavelet transform measures gray level variations on different scales. The edges of the image structures are given with sharp variation on a slowly variable background. The variation in resolution enables the wavelet transform to zoom into these image irregularities. Visibility of these irregularities depends on HVS sensitivity, and according to [5] one can calculate wavelet coefficients which correspond to the visibility threshold.

It can be assumed that the tile surface failures produce some spots in the tile image. Spot with the luminance different than local mean luminance, with sharp edges, correspond to the sharp contrast. It can be detected from the local maxima of the wavelet transform [6], which do not exist for the image of the tile without failures [7].

Diagnostic algorithm

The processing algorithm consists of two parts. The first part tests the influence of the failure contrast and size on failure detection (Fig.2). The second part applies the experience from the first part to the

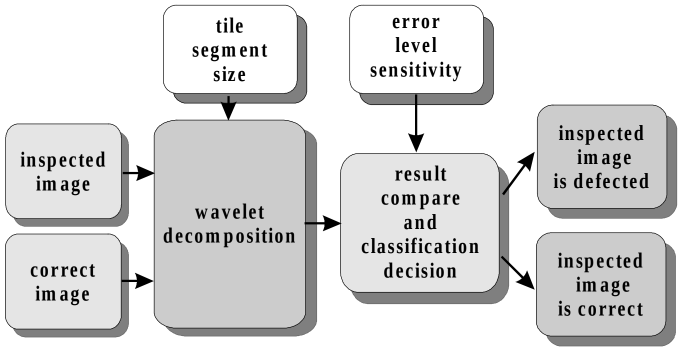

Fig.2 Block diagram of the diagnostic algorithm for changing failure contrast and defect size.

real surface failures. The algorithm for changing defect contrasts and defect size processes the images of good tile and tile with failures. The images are divided to segments and DWT is applied to them. The decision of the failure is made by comparing the wavelet coefficients of the tested segment of the good image and image with failures (4). An error is detected if the determined detection sensitivity level (DSL) is less than the relative difference between wavelet coefficient maximums for reference image and the inspected image.

$$DSL \leq \left[\frac{\max|X_{V,1}| - \max|X^*_{V,1}|}{\max|X_{V,1}|} \quad or \quad \frac{\max|X_{H,1}| - \max|X^*_{H,1}|}{\max|X_{H,1}|} \quad or \quad \frac{\max|X_{D,1}| - \max|X^*_{D,1}|}{\max|X_{D,1}|} \right] \Rightarrow \begin{matrix} error \\ \det ected \end{matrix} \qquad (4)$$

In this equation the $X_{V,1}$, $X_{H,1}$ and $X_{D,1}$ are the subbands with wavelet coefficients of the reference image and $X^*_{V,1}$, $X^*_{H,1}$ and $X^*_{D,1}$ are the subbands with wavelet coefficients of the inspected image, at the first decomposition level.

The image processing algorithm is realized using Matlab package with wavelet and image procesing toolboxes. The images of the referent tile and the tested tile used in image processing are in bitmap format.

The detailed description of that algorithm is done on Fig.3. One block is cut from the referent picture without defects and it is named referent segment. The same is done with the tested image, the picture wirh surface failures. Both segments have the same size and position on the image. Both segments are processed by DWT , so that the coefficients of the picture segment detailes are produced.

These coefficients contain the information about image diversity in three directions: horizontal, vertical and diagonal. The segment processing result gives the information about the existence of the failure based on the comparing of the horizontal, vertical and diagonal coefficients in both segments. The processed tested segment is proclaimed as defect segment based on the amount of the difference between corresponding coefficients in both segments.

The diagnostic algorithm beginns with loading of the referent and tested image. The processing parameters are set after that: **bs, $\mathbf{grs_{min}}$, $\mathbf{grs_{max}}$,** and $\mathbf{grs_{step}}$. The segment size is defined by parameter

bs. It has the direct influence to the processing time. The higher amount of the **bs** parameter decreases the processing time, but increases the possibility of nondetecting the failure in that segment. The lower amount of the **bs** parameter increases the processing time, but increases the possibilty of detecting the failure in that segment.

The parameter **grs** describes the tolerance level of the difference between coefficients in both segments. The parameters **grs_{min} , grs_{max},** and **grs_{step}** define the interval in that the difference between coefficients on both segments is analysed. The lower amount of **grs** gives the better method sensitivity, but increases the number of mistakes in segments proclaiming faulty, that are not containing failures. The higher amount of **grs** produces the higher tolerance level and increases the possibility of nondetecting the segment failure.

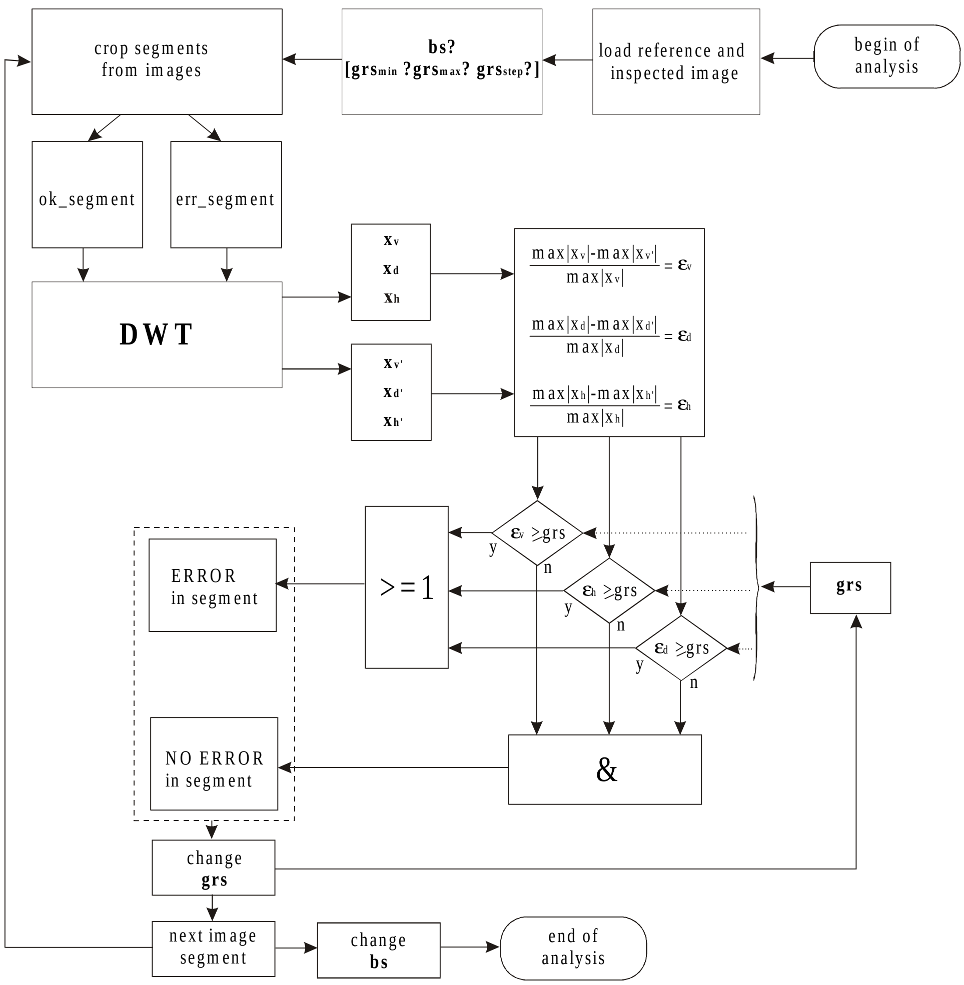

Fig.3 The detailed image processing diagram for Matlab application.

After the initial setting of parameters the algorithm starts the analysis. From the both images, the referent and tested image, the segments, which size is defined by the parameter **bs,** are cut. They are cut at the same position in both images. Discrete wavelet transform is applied to both segments, resulting in horizontal, vertical and diagonal coefficients. The coefficients with maximum amount are selected and used to calculate the differences ε between corresponding coefficients on both images. Theese differences are compared with the tolerance level **grs**. If the difference is higher tehan the tolerance level the tested segment is proclaimed as defect segment. The segment is proclaimed defect segment if any one from the differences ε_h , ε_v or ε_d is higher than the tolerance level. The segment is proclaimed correct if all of the differences are lower than the tolerance level. The analysis for one value of the tolerance level **grs** is finished. The tolerance level is increased for the value $\mathbf{grs}_{step}$ and the analysis of the same segment will be repeated.

The tested segment is analysed using the values for the tolerance level **grs** from the interval [$\mathbf{grs}_{min}$, $\mathbf{grs}_{max}$]. After that the new segment is cut and analysed till the whole image is analysed. The new value for **bs** is used and new segment size is defined for the same image and the analysis is repeated. Such analysis gives the values for segment size **bs** and the tolerance level **grs** that gives the best results in the image defects detection.

Experimental algorithm evaluation

Artificial surface defects

The algorithm is verified by artificially made surface failure on the image. The image size is 1200*1500 pixels and the segment size is 47 *47 pixels. The failure size changes from 1-15 pixels, and the failure contrast changes from -70 to +70 referred to the average value of the segment brightness of the good image.

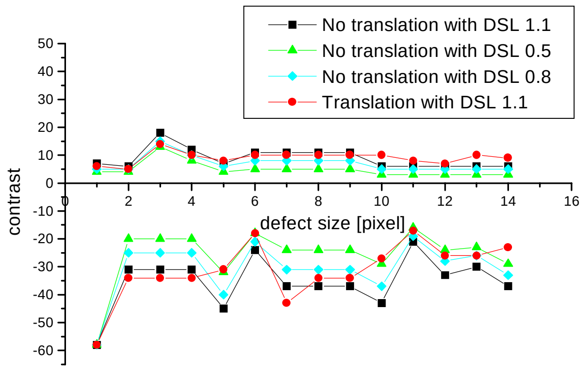

Fig. 4 Relationship between the contrast of defect and defect size.

The results for several DSL are presented on Fig.4. The insensitivity area is defined between the upper and lower curve. The lowest curve presents the result for the translated image. This algorithm detects better failures brighter than its environment. The diagnostic algorithm applied to inspect image is similar to the first one. Instead the changes in failure contrast and size the DSL and segment size are defined based on former experience. The wavelet decomposition is performed to the each segment. The decision of the segment failure is made based on DSL.

Evaluation using real images

The influence of the segment size to the analysis results are presented on Fig.5. The segment size is described by VK for the block sizes 35x35, 47x47 and 65x65 pixels. The values of detection sensitivity level lower than 1,7 are not used. The estimation of the best DSL is done for used segment size after the whole image is processed and the failure segments are detected. From this diagram it is possible to see that the smaller segments (35x35) gives the bigger difference between the proclaimed defect segments and real number of defect segments than the greater segments at the same DSL. In the same time the processing time increases and the sensitivity of detecting the failures is bigger. One of the conclusions from the diagram could be that it is better to use bigger segments, because of the smaller difference or mistakes and shorter processing time.

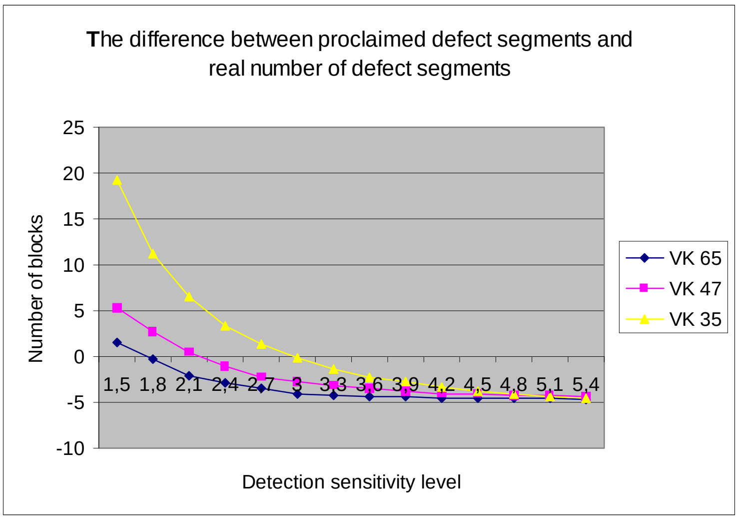

Fig. 5 The difference between proclaimed number of defect segments and real number of defect segments as a function of detection sensitivity level for three segment sizes.

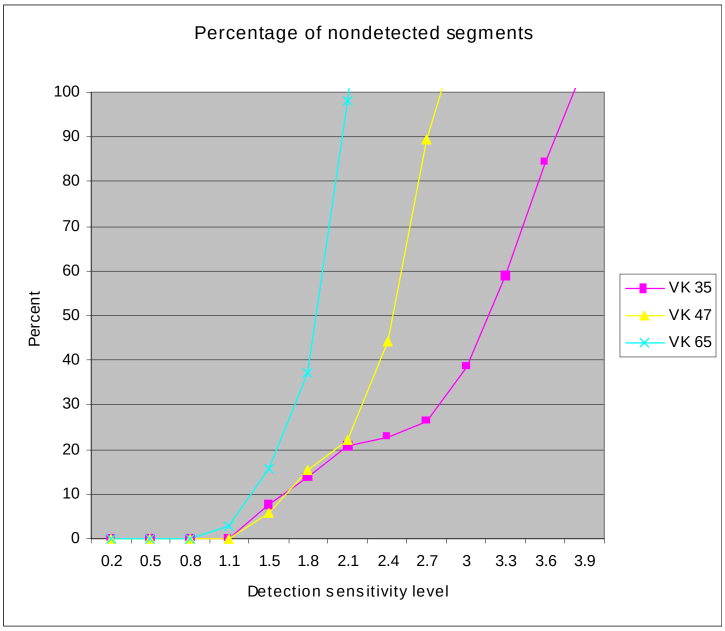

Fig.6 The percentage of nondetected segments as a function of DSL for three block sizes.

But from the diagram on Fig.6 is clear that bigger segments means bigger percentage of nondetected failures, what is very important for the application. It is better to have false proclaimed segments than to have nondetected segments and to leave the tiles with surface failures in higher class. So it is necessary to optimize the DSL and segment size to get better results in visual inspection.

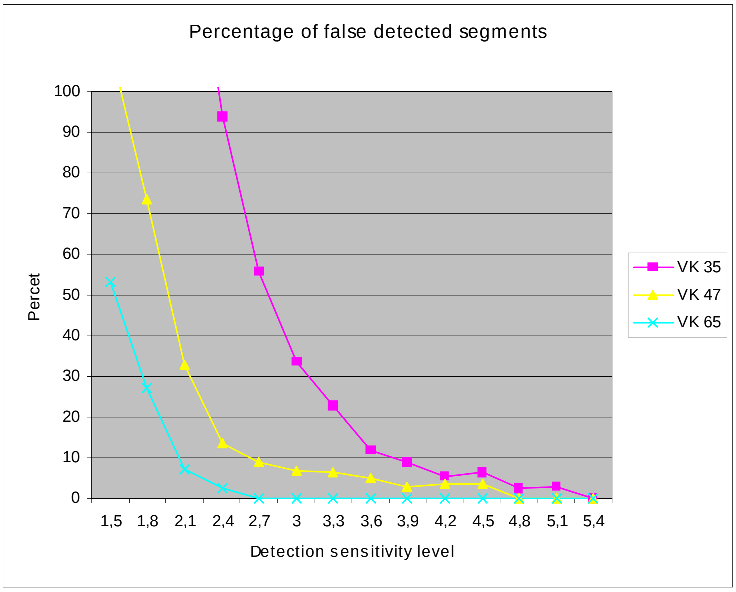

Fig.7 The percentage of mistakes in proclaiming the defect segment as a function of DSL.

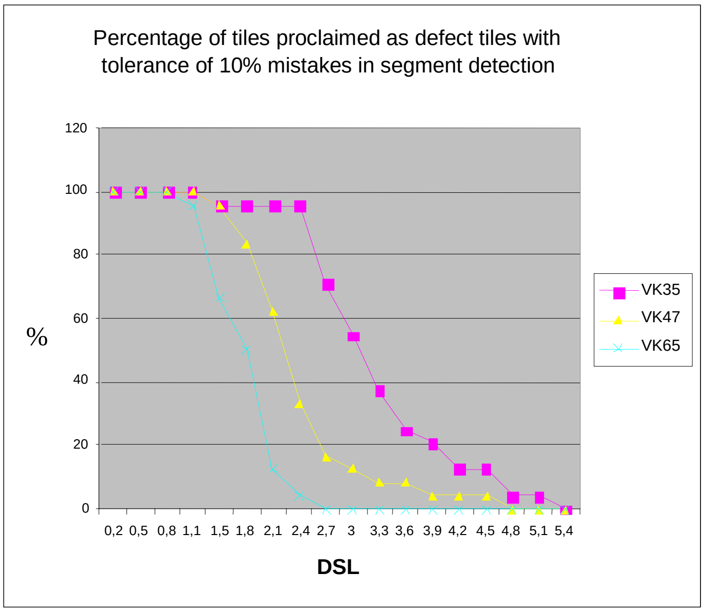

Fig.8 The percentage of the tiles that are proclaimed as defect tiles using the tolerance of maximally 10% of mistakes in alnalysing segments.

Conclusion

The image processing used for visual inspection and quality control in serial production is described in this paper. It is based on the discrete wavelet transform method. The described diagnostic algorithm is based on comparing of the wavelet coefficients of the original image without defects and replica images on that the defects are expected. The algorithm evaluation is done on two ways: using the artificial surface failures and using the real images with surface failures. The research is made trying to find the influence of the DSL and segment size to the number of detected failures.By continuing the research of the connection between the segment size and DSL for each type of surface failure it could be made efficient system for quality control and failure classification in automated production process.

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