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Intelligent Machine Vision System for Automated Quality Control in Ceramic Tiles Industry

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Intelligent system for automated visual quality control of ceramic tiles based on machine vision is presented in this paper. The ceramic tiles production process is almost fully and well automated in almost all production stages with exception of quality control stage at the end. The ceramic tiles quality is checked by using visual quality control principles where main goal is to successfully replace man as part of production chain with an automated machine vision system to increase production yield and decrease the production costs. The quality of ceramic tiles depends on dimensions and surface features. Presented automated machine vision system analyzes those geometric and surface features and decides about tile quality by utilizing neural network classifier. Refined methods for geometric and surface features extraction are presented also. The efficiency of processing algorithms and the usage of neural networks classifier as a substitution for human visual quality control are confirmed.

Inteligentni sustav strojnog vida za automatiziranu kontrolu kvalitete keramičkih pločica

Izvornoznanstveni članak

U članku je prikazan automatizirani sustav za vizualnu kontrolu kvalitete keramičkih pločica uporabom strojnog računalnog vida. Proces proizvodnje keramičkih pločica u gotovo svim svojim fazama zadovoljavajuće je automatiziran, osim u fazi kontrole kvalitete, na kraju procesa. Kvaliteta keramičkih pločica provjerava se i ocjenjuje postupcima vizualne provjere kvalitete, gdje se ljudski čimbenik nastoji zamijeniti sustavom strojnog računalnog vida u funkciji povećanja kvalitete i povećanja efikasnosti proizvodnje. Kvaliteta keramičkih pločica definirana je dimenzijama i površinskim značajkama. Predstavljeni sustav strojnog vida analizira geometrijske i površinske značajke te odlučuje o kvaliteti keramičkih pločica na temelju navedenih značajki uporabom klasifikatora s neuronskom mrežom. Predstavljene su također i metode koje poboljšavaju izdvajanje geometrijskih i površinskih svojstava. Potvrđena je efikasnost obradnih algoritama i primjena neuronskog klasifikatora kao zamjene za vizualnu kontrolu kvalitete ljudskim vidom.

Keywords
Ceramic tiles
Machine vision
Neural networks
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Quality control

Ključne riječi
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1. Introduction

There are industrial processes that use or require visual inspection in quality control as an integrated part of their production stages. Such processes are based on visual perception principles to successfully determine levels of product quality by quantify its visual appearance in general and some specific visual features, respectively [1]. A visual inspection system is based on machine vision principles by usage acquisition cameras and also, one or more crunching computers. Main motivation for machine vision implementation is because of economic factors that constantly requires less production costs. One of processes that use machine vision for product quality control is the production process of ceramic tiles [2]. The production phases are more or less automated . The exception is quality control stage with mostly human vision inspection. Some ceramic tiles plants still uses human vision in quality control. The main reason lies in complexity of this task. Human resources are used because the visual quality control process is very complex and highly demanding and often should be on-line adaptive on changeable quality requests in classification stage of production. Because of human features limitations as controlling element in production line, man becomes one of the weakest and unreliable link. By replacing the human with machine, the whole process should have better production yield and could be more efficient [3].

Symbols/Oznake

μ_N	- mean value of intensity - srednja vrijednost intenziteta	i, j	- image elements indexes - indeksi elemenata slike
σ^2_N	- variance - varijanca	H_N	- histogram vector - histogram vektor
E_N	- djelotvorna širina pri posmičnom proboju stijenke profila - effective width for punching shear	N	- Image block index - indeks bloka slike
E	- energy - energija	d	- image block size - veličina bloka slike
ΔE	- quantified feature - kvantizirana značajka	I'	- image matrix - matrica slike
K_N	- entropy - entropija	$\vec{U}_G$	- geometrical features vector - vektor geometrijskih značajki
B_N	- contrast - kontrast	$\vec{U}_S$	- statistical features vector - vektor statističkih značajki
C_N	- correlation - korelacija	y	- tile class, NN output - klasa pločice, izlaz iz NN mreže
p	- probability coocurence matrix - matrica vjerojatnosti pojavnosti		

The quality of ceramic tiles is defined by international standards containing very demanding criteria. The standard prescribes criteria that define ceramic tiles classes depending on amount and type of ceramic tiles failures [4].

Many machine vision systems for ceramic tiles quality control are developed and described until today, but the most representative and basic are described [5-8]. Almost all proposed systems aren't flexible enough and can't handle various types of ceramic tiles with different surface design. This paper presents an automated machine vision system for ceramic tile quality control that utilizes neural network based classifier for higher flexibility according constantly changing demands in versatility of tile surface design [9,10].

1.1. Machine vision setup

Machine vision system for ceramic tiles quality control consists of at least two digital cameras and computer. For high performance systems one computer isn't enough, so often two or more computers are used for image processing. The basic element of machine vision system is computer with digital cameras through standard or often specific signal interfaces, Figure 1. Typical machine setup is given by Figure 2. This machine vision setup uses two digital cameras and one processing computer. Both cameras are line scan cameras where angled camera is B/W and orthogonal one is color camera. The angled camera acquires image of reflected light from tile surface to detect surface structural defects like lumps, bumps, scratches and other defects that are dominant. This camera is used for measuring tile dimensions by registering tile outline, Figure 3. So, *B/W* angled camera has higher resolution than orthogonal color one.

The orthogonal color camera acquires only the tile surface image in its full color spectrum, Figure 4. This image is used for further analysis where dominant color of tile is checked and surface content analyzed in order to find any production flaws or material composition

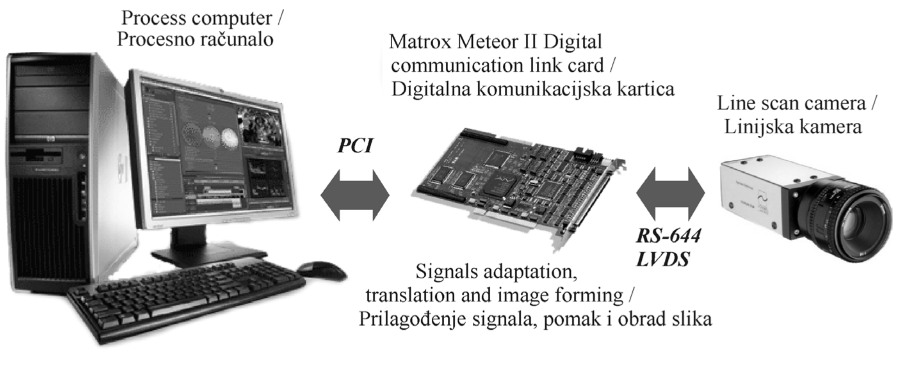


Figure 1. Basic system setup for machine vision: computer - communication interface – digital camera

Slika 1. Temeljna sastavnica sustava strojnog vida: računalo – komunikacijsko sučelje – digitalna kamera deficiencies. The minimal configuration consists of those two line scan cameras.

Table 1. The characteristics of line scan cameras

Tablica 1. Značajke digitalnih llinijskih kamera

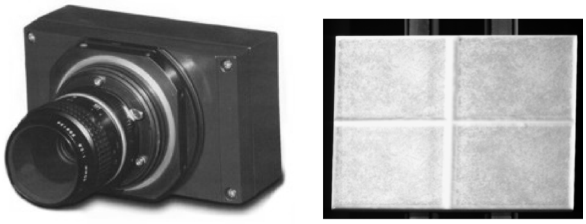
Parameter / Parametar	UniLine-2048	OZF-1728
Type / Vrsta	B/W Line scan / Skenirana linija	Color Line scan
Resolution / Razlučivost	1×2048 px	3×1728 px
Sensor size / Veličina osjetnika	28.7mm	36.3 mm
Pixel geometry / Dimenzije piksela	14μm × 14 μm	7 μm × 21 μm
Light sensitivity / Osjetljivost na svjetlo	$40 \ \frac{V}{lx \cdot s}$	$\begin{bmatrix} R: & 3.7 \\ G: & 5.5 \\ B: & 2.2 \end{bmatrix} \frac{V}{lx \cdot s}$
Scan speed / Brzina skeniranja	4,7 kHz	1,71 kHz
Comm. link / Kom. veza	RS-644 LVDS	TTL RS-422

a) B/W line scan camera / Crno-bijela linijska kamera

b) Acquired image (tile outline only / Snimljena slika (samo konturni obris pločice)

Figure 3. Angled *B/W* camera, Optisens UniLine-2048

Slika 3. Pod nagibom postavljena, crno-bijela kamera, Optisens UniLine-2048

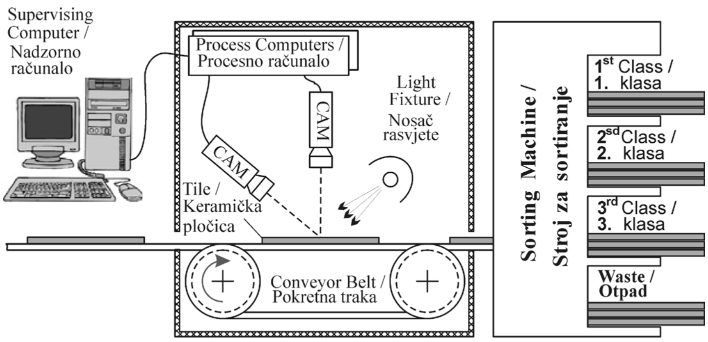


a) Color line scan camera / Linijska kamera u boji

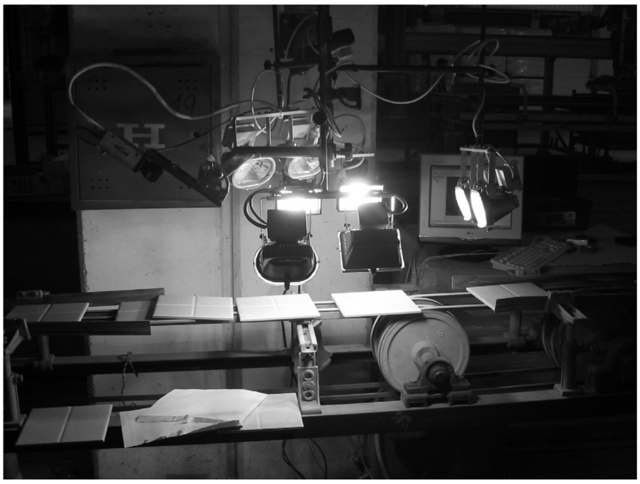
b) Acquired image / Snimljena slika

Figure 4. Orthogonal color camera, Optisens OZF-1728

Slika 4. Okomita, kamera u boji, Optisens OZF-1728



a) Principal view of machine vision system setup with two digital cameras and one processing computer / Principijelni strukturni prikaz sustava strojnog vida sa dvije digitalne kamere i jednim procesnim računalom



b) Actual system setup for ceramic tiles quality control / Izgled sustava za kontrolu kvalitete keramičkih pločica

Figure 2. Machine vision system setup for ceramic tile quality control

Slika 2. Sustav računalnog strojnog vida za kontrolu kvalitete keramičkih pločica

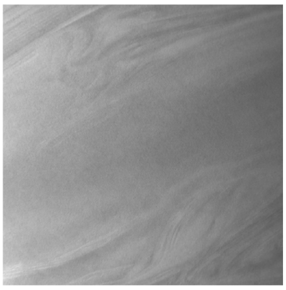
The camera characteristics affect on system performances and can be improved in conjunction with processing computer performances. According to parameters shown in Table 1 maximum acquisition performance defines the slowest camera. The minimum resolution of acquired image defines the smallest possible defect that could be visible. According to human eye resolution of highly contrast objects follows the minimal object size 0.2-0.5 mm (looking the ceramic tile from distance of 0.5-1m). The color camera has the lowest performance and defines acquiring resolution of 1728 pixels width and infinite in length. The length of image is defined by tile dimension and may vary from 100 to several thousands of pixels. The used tile dimensions are given in Table 2.

Table 2. The image features and tile dimensions

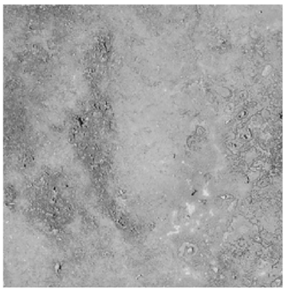
Tablica 2. Svojstva slike i dimenzije pločica

Witdh / Širina, cm	Length / Dužina, cm	Pixel pitch / Veličina piksela, mm	Capture time / Vrijeme snimanja, s
15	15	0.20	0.5
20	20	0.25	0.6
20	25	0.25	0.7
30	30	0.30	0.7

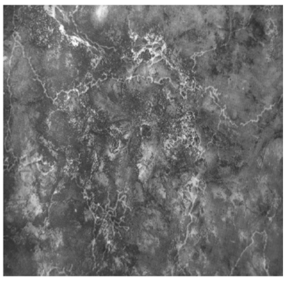
a) without texture / bez teksture



b) lightly textured / slabo teksturirane



c) medium textured srednje tekturirane



d) highly textured jako teksturirane

Figure 5. Tile types classification by surface textural dynamics

Slika 5. Klasifikacija vrsta pločica prema texturnoj dinamici

2. Image analysis and feature extraction

The acquisition of image is just the first step in whole analysis process. Real job begins just after image acquisition. As first the image should be trimmed optically using the parameters defined by ceramic tiles surface design. There are four types of tiles according to surface design and composition/textural dynamics as on Figure 5:

- without texture → plain tiles, uniform tiles (Figure 5a)
- lightly textured → weak textural dynamics (Figure 5b)
- medium textured → mild textural dynamics (Figure 5c)
- highly textured → strong textural dynamics (Figure 5d)

The trimming process covers the basic image preprocessing steps like tone and contrast equalizations for lighting output inconsistence elimination, elimination of object barrel or pincushion distortion (HF filter for light and movement jittering),rotation and translation to referent position and cropping out the tile image without background from acquired image generating secondary set of images. One set of images is prepared for dimensional analysis and the second, cropped one, for surface error analysis.

2.1. Dimensional analysis

The dimensional analysis covers geometric checks of tiles. Geometric features of ceramic tiles are:

- Tile size → width and length
- Shape regularity → diagonality, shape distortions
- Corner and edges presence → corner and edge defects
- Edge linearity

The numbers of methods are developed for dimensional analysis [11-15]. The used methods mostly relies on algorithms for strait lines detection by using Hough transform where strait lines are detected and its intersection interpolates corner positions. By direct comparison of Hough lines and real tile the edge linearity could be calculated. Diagonal and shape distortion are calculated from corners position as on Figure 6.

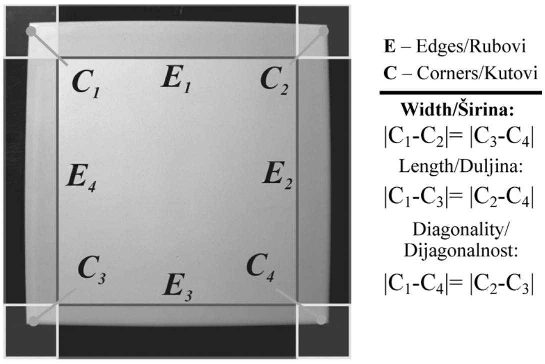


Figure 6. The geometric features of tile

Slika 6. Geometrijske značajke pločice

Due to high resolution of acquired images, the algorithms based on Hough transform have poor performance. The usage of Hough transform is simple and clean way to retrieve tiles geometric feature, but time consuming, what is unacceptable for real time application such as machine vision quality control. The new method is developed based on contour tracing principles, to avoid Hough transform analysis drawback, Figure 7, [16]. This method aggregates several, ordinarily separate, procedures into single analysis procedure where concurrently are checked all tile geometric features within acceptable time limits. Basic idea of this method is to use directional tracing of tile contour and register unacceptable differences against modeled trace function of reference tile contour.

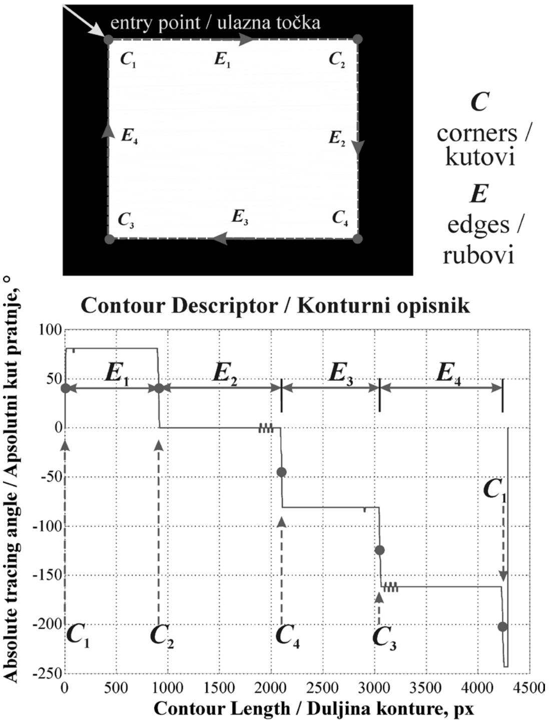


Figure 7. Directional contour description

Slika 7. Usmjereno opisivanje obrisa

For ceramic tile 200×250 mm with one edge defect by direct comparison of reference and analyzed contour descriptor this method easily finds and localize defect in less than 0.5 s (by utilizing multicore processors analysis time can be reduced below 100 ms), Figure 8. The amount of differences between reference and analyzed descriptor gives size of detected defect.

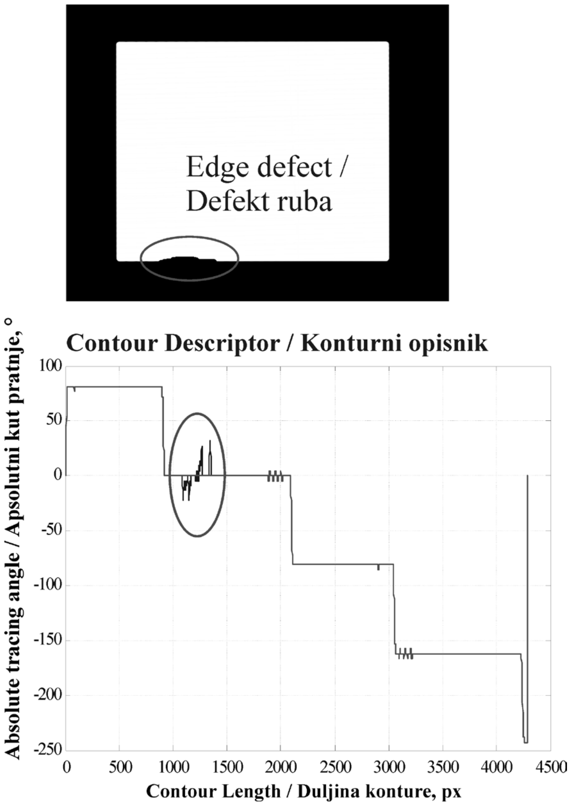


Figure 8. Edge defect detection and localization

Slika 8. Detekcija i lokalizacija oštećenja ruba

2.2. Surface analysis

The surface analysis covers detection of surface defects. Surface analysis methods are divided into two groups:

- Surface defects detection,
- Tonality and chromacity inspection.

Surface defects detection analysis covers surface structural defects like dot-shaped defects, line-shaped defects, blob defects and texture overall structural integrity. Tonality and chromacity inspection measures levels of tonality discrepancy and color deviation against the reference tile. Some methods are developed for this purposes [17-19]. For this machine vision setup a group of 1st and 2nd order statistically oriented methods is developed in conjunction with Euclid image segmentation analysis. Used methods are segmented histogram and GLCM analysis where following statistic parameters are observed:

- Mean value of intensity, μ_N,

$$\mu_N = \sum_{i=0}^{255} \frac{i \cdot H_N(I'(N))}{d^2}, \tag{1}$$

- Variance, σ^2_N,

$$\sigma^2{}_N = \sum_{i=0}^{255} (i - \mu_N)^2 \frac{H_N(I'(N))}{d^2}, \tag{2}$$

- Energy, E_N,

$$E_N = \sum_{i=0}^{255} \frac{H_N(I'(N))^2}{d^4}, \tag{3}$$

- Entropy, K_N,

$$K_N = -\sum_{i=0}^{255} \frac{H_N(I'(N))}{d^2} \cdot log_2 \left(\frac{H_N(I'(N))}{d^2} \right). \tag{4}$$

For Haralick GLCM matrix additionally the following parameters are evaluated:

- Contrast, B_N,

$$B_N = \sum_{i=0}^{G-1} \sum_{j=0}^{G-1} (i-j)^2 \cdot p(i,j), \tag{5}$$

- Correlation, C_N,

$$C_N = \sum_{i,j=0}^{G-1} p(i,j) \left(\frac{(i-\mu_i)(j-\mu_j)}{\sqrt{\sigma_i^2 \sigma_j^2}} \right). \tag{6}$$

Where, i is index of intensity level, N is index of analyzed image segment, $H(N)$ is histogram vector (or GLCM probability matrix) of N-th image segment, d is analyzed segment window size, p is probability coocurence matrix.

For each image segment totally 14 statistic parameters are calculated. Ten of them are parameters calculated form *B/W* image where surface consistence are described through this statistical values and other four parameters (mean, variance, energy and entropy) are related color tile image where tonality and color properties are analyzed.

3. Neural network classifier

Each ceramic tile can be inspected by dimensional and surface features. Problem arises with pseudo random texture pattern (or rarely, fully randomized texture pattern) where is hard to recognize specific features. To successfully classify such tiles it should be used flexible and adaptive classifier, that can successfully handle large variations in surface statistic features. The logic solution is neural network based classifier. It can handles various types of features, geometric and statistic [20]. For its proper functionality machine operator should teach the adaptive algorithm with set of various groups of ceramic tiles and clearly differ each tile class.

3.1. Feature quantization

The geometric features are in form of scalars. Each tile has a geometric feature vector consisting of geometric feature scalars. It is not the case with surface features. Due to Euclidian image segmentation and analysis, the surface features can not be arranged in form of vector where each scalar represents an unique statistic feature. Each image segment generates a vector of statistic features and one complete image generates matrix of features. Due to geometric and statistic feature the vector nonalignment in sizes is used a method for feature quantification. This quantification reduces feature number, for statistical features only, from matrix to vector of scalars by replacing a vector of each statistic feature with corresponding scalar.

The method used for feature quantization calculates absolute difference between actual quantification feature vector and tolerant feature deviation area according class designation, Figure 9. The equivalent scalar value of quantified feature is calculated by expression

$$E = \sum_{i=0}^{N} \Delta E(i), \tag{7}$$

where N represents the length of quantified feature vector and corresponds to the number of analyzed image segments.

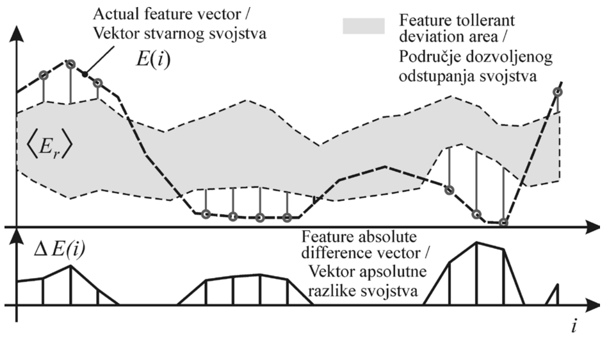


Figure 9. Feature vector quantization

Slika 9. Kvantizacija vektora značajki

3.2. Neural classifier

The object features presence or absence characterizes its quality. The volume and type of these features depend on type of tile. Some ceramic tiles differ significantly in amount of features from two classes of the same tile (especially when pseudo-random texture type of tile is analyzed). The vast diversity in classifying rules makes hard task for a classification algorithm, so neural network based classifier seems logical solution for this purpose. It is used the simplest neural network topology where neural network structure is based on one input layer, one hidden layer and one output neuron layer, Figure 10.

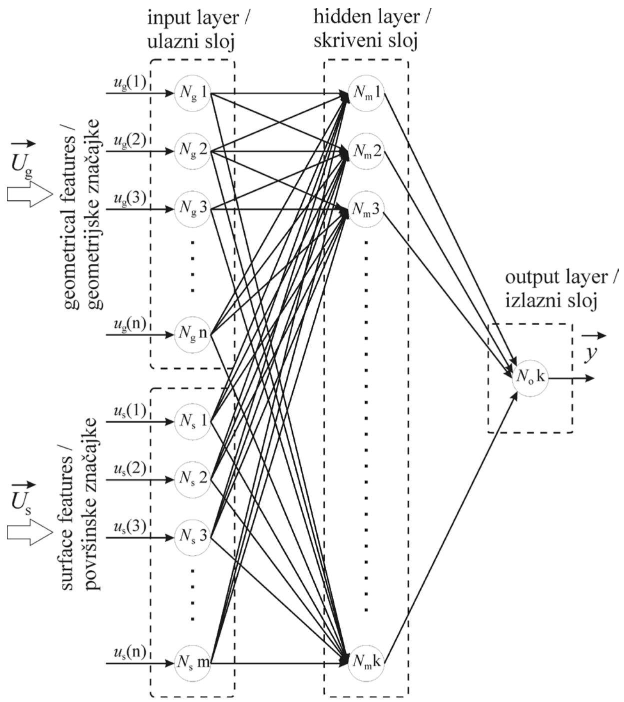


Figure 10. Neural network based classifier topology
Slika 10. Topologija neuronskog klasifikatora

The input layer neurons are divided into two groups of input sets. These two input sets comply to logical division of ceramic tile features: one group accepts tile geometric features, $\vec{U}_G$, and the other group contains surface statistic features, $\vec{U}_S$. The output layer neurons give as a result a vector $\vec{y}$, that corresponds to the number of classes, four neurons for four classes. For proper work of neural network classifier the set of tiles should be analyzed and feature extracted to create the training data corresponding to tile types and its class designation.

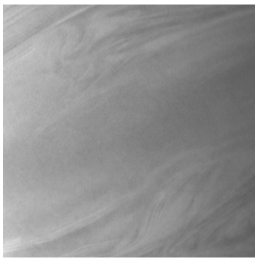
4. Experimental results

The machine vision setup used for experiment was tested in factory KIO keramika d.o.o. in Orahovica. It consists of the following components as on Figure 2:

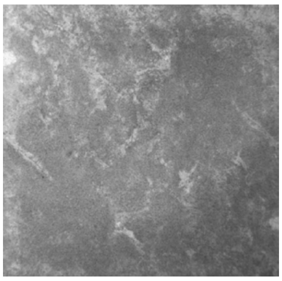
- Two line scan cameras – B/W and color, with parameters given in Table 1.
- Light source – HF cold daylight fluorescent set.
- Processing computer – single core, P4 Intel topology on 3.2 GHz with 2 GB of RAM and RS-644 LVDS and RS-422 interface cards.
- Variable speed conveyor belt – a part of production line.
- Set of four ceramic tile types with known classes.

First, ceramic tile acquisition environment and conditions is adjusted according camera with weakest electro-optical characteristic, which is OZF-1728. Four types of tile are used according its textural dynamics, Figure 11.

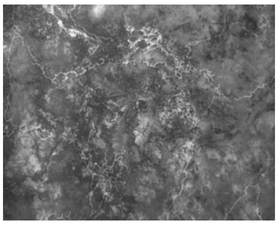
Name / Ime: “Lili 3”
Dimension / Dimenzija: 15x20 cm
Type / Tip: plain tile
Capture time / Vrijeme snimanja: ~0.6s
Image res. / Razlučivost slike: 1728x1000 px
B/W: (2048x1180 px)



Name / Ime: “Sky Gray” / Nebeski siva
Dimension / Dimenzija: 20x20 cm
Type / Tip: lightly textured
Capture time / Vrijeme snimanja: ~0.6s
Image res. / Razlučivost slike: 1728x1000 px
B/W: (2048x1180 px)



Name / Ime: “Malaga Brown” / Malaga smeđa
Dimension / Dimenzija: 20x20 cm
Type / Tip: medium textured
Capture time / Vrijeme snimanja: ~0.6s
Image res. / Razlučivost slike: 1728x1000 px
B/W: (2048x1180 px)



Name / Ime: “Iris plava” / Iris plava
Dimension / Dimenzija: 20x25 cm
Type / Tip: highly textured
Capture time / Vrijeme snimanja: ~0.7s
Image res. / Razlučivost slike: 1728x1200 px
B/W: (2048x1450 px)

Figure 11. Tile types and characteristics used for experiment
Slika 11. Vrste i karakteristike pločica korištenih u eksperimentu

Acquisition times and image resolutions for each tile are shown in Figure 11. After image acquisition the first step in analysis is to check geometrical features. Geometrical features analysis is done by using directional contour tracing described in 2.1. where in same time are characteristics geometrical features and corner/edge defects checked. Surface analysis is done through using 1st and 2nd statistical analysis of image segments as is described in 2.2. The results of geometrical feature extraction and surface feature description are shown in Table 3 where only performance results are shown because for this stage the geometrical and surface statistical features can't directly and precisely describe tile class dependency.

Table 3. Performances of geometry and surface analysis

Tablica 3. Performanse geometrijske i površinske analize

Tile Name / Naziv pločice	Geometry analysis / Geometrijska naliza, s	Surface analysis / Analiza površine		Total / Ukupno, s
		1st order, s	2nd order, s	
Lili 3 / Lili 3	0.42	2.4	6.3	9.12
Sky Gray / Nebesko siva	0.48	3.2	8.4	12,1
Malaga Brown / Malaga smeđa	0.48	3.3	8.4	12.1
Iris blue / Iris plava	0.51	4.1	10.5	15.1

For proper determination of tile class dependency the neural network classifier is used. Classifier topology complies with Figure 10. where following *NN* setup is used:

- 19 input neurons – 5 for geometry features (width, length, diagonality, edge linearity and presence of corner/edge defects) and 14 for surface features
- 10 neurons in hidden layer
- 4 neurons in output layer – each neuron complies with one tile class where are defined 1st class, 2nd class, 3rd class and waste.
- back propagation teaching method is used
- bipolar sigmoidal activation function is used for all neurons, (2).

$$y = \frac{2}{1 - e^{-x}} - 1. \tag{8}$$

Referenced set of tiles with class dependency and tile type is shown in Table 4. Those tiles and classes are defined by a subjective quality perception of a human classifier.

Table 4. Class structure of analyzed tile types

Tablica 4. Struktura klasa analiziranih pločica

Tile type / Naziv pločice	Analytic set of tiles / Analitički skup ločice			Total / Ukupno, tiles
	1st class	2nd class	3rd class	
Lili 3 / Lili 3	35	28	7	70
Sky Gray / Nebesko siva	21	43	26	90
Malaga Brown / Malaga smeđa	16	35	18	69
Iris plava / Iris plava	18	33	21	72

After teaching neural network classifier and minimizing its teaching error to less than 1 % in total (the best result it could be achieved with presented *NN* setup) the verification of result is proven. Prove procedure consist only from tiles which are 1st, 2nd and 3rd class with no waste designated tiled. The results are shown in Table 5.

Table 5. The false detected class dependency

Tablica 5. Krivo klasirane pločice

Tile type / Naziv pločice	Percentage of false detected tile classes / Postotak krivo detektiranih klas pločica		
	1st class	2nd class	3rd class
Lili 3 / Lili 3	+8.5 %	-21 %	+42 %
Sky Gray / Nebesko siva	+52 %	-16 %	-15 %
Malaga Brown / Malaga smeđa	+18 %	-3 %	-11 %
Iris plava / Iris plava	0 %	-15 %	+24 %

The results in Table 5 show how many tiles are false detected according its real class dependency. According to these results usually the 1st class has surplus in detected tiles and 2nd class has shortage of its. 3rd class often is waste class and results shows that "Lili 3" and "Iris plava" tile by using this NN classifier will have more production losses, what negatively affects on process economy. On the other side, "Sky Gray" and "Malaga Brown" will have better production yield, but less quality overall because more lower class tiles will be pronounced as 1st class tiles. Looking overall classifying results it could be concluded that proposed *NN* classifier doesn't do its job well but the analytic tile set and prove analytic set of tiles is chosen and structured by human classifier. The tendency is that two different man cannot agree what is 1st class, 2nd class or 3rd class of tiles on same way. So, possible explanation of poor *NN* classifier results can be explained by inconsistency of classes of analytic and prove tile sets.

5. Conclusion

The presented machine vision system has purpose to replace a human vision quality controller in ceramic tiles industry. Presented system consists of at least two cameras for image registration and one computer. After the image acquisition and trimming basic optic parameters the geometric and surface analysis has been done. Geometric analysis relies on contour tracing method where several geometric inspection methods are united into one. By usage of this method the complete analytic time is reduced to acceptable amount limits suited for real time operations. This analysis time of approx. 0.5 second is to slow for real systems, but with further algorithm optimization this time can be reduced by factor 10. After analysis and finding geometric features of ceramic tile the surface analysis has been done. Surface analysis is complex analysis. Because of large resolution images there is huge amount of data to be analyzed and proper features extracted. As main group of methods there are statistically based methods. By usage of these methods we cover one significant problem that existing similar automated solution can hardly handle with. This problem shows how to process fully randomized and pseudo randomized textured tiles. By usage of statistically oriented surface analytic methods we describe tile surface with dozens of statistical features.

Statistical methods handle with vast amount of data what takes significant amount of time necessary for complete analysis. Another problem is how to unique describe analyzed tile and its analyzed feature with scalar formed value. We handle it through feature quantization method where analyzed feature gives scalar formed value. The entire statistical methods still takes to much time for its calculating. One computer can not handle it properly and has no enough power for real time crunching. The solution is in fact of future algorithm optimization for better utilization of multicore processors and utilization of multi-computing and distributed systems such computers grid or cloud computing. Expected time reductions are by factor >20 what should reduces necessary time to acceptable 200 ms or less.

One other problem exists, how to interpret those calculated results because statistical parameters does not mean much by itself and can not be directly connected, each of them, for specific surface property. For this purpose a neural network based classifier is used. NN classifier interprets those results according to teaching parameters learned during network training with set of desired tiles and its classes. The simplest topology of *NN* classifier is used where hidden layer has only 10 neurons. Increase of hidden layer neuron number has no much effect on classifying accuracy. The results given in Table 6. could be improved by extension of *NN* topology by adding the additional hidden layer with certain number of neurons. The NN classifier performance can be improved by usage of extended sets of surface statistical parameters by introducing new set of statistical features that are not covered in this existing parameter set. The problem with classification occurs even with set of analytic tiles and their classes for *NN* training purposes, where class inconsistency appears during different subjective perception capability of human vision classifier. The problems can not easily be avoided and there are many struggles today to define and standardize ceramic tiles class dependency parameters. Until this issue resolves the machine vision system for ceramic tiles quality control will be only partly automated.

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