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Colour and proportion of grains measurement in through-body porcelain tiles by means of image processing

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Abstract

A common demand in the production of through-body porcelain tiles is the visual uniformity of the produced tiles. We assume that their visual appearance can be controlled by properly acting over the process control. This paper presents an image processing method for obtaining a feedback for it. The method estimates two important properties, which are colour and proportion of each kind of grains forming the tile. It consists of two steps: a colour segmentation by applying the clustering algorithm 'Fuzzy C-Means', and the centres refinement of the former segmentation, proposed by us. The centres refinement proposal is based on the colour information and the colour mixing process. The experimental results show that the measurements of the colour and the proportion of grains obtained with the centres refinement, are more accurate compared to the ones obtained with 'Fuzzy C-Means'.

Keywords: Colour; Porcelain; Image processing; Tiles

1. Introduction

A common demand in the production lines of through-body porcelain tiles manufacturing process is to achieve the best possible visual uniformity in the produced tiles. The objective is that the tiles, once placed and fixed on the floor, do not present noticeable differences to the human eye.

The typical solution to this problem is to classify the produced pieces. The tiles are grouped into lots, in a manner that any two pieces from the same lot look uniform to the human eye. The classification is done, either manually by a specialized operator, or automatically.

Another possible solution consists of acting directly over the production process, by means of a control system that, after obtaining a feedback of the visual appearance of the tile, would act conveniently over the variables affecting it.

This paper focuses on this second option, particularly in the analysis of variables that influence the visual appearance of through-body porcelain tiles. These variables are colour and the proportion of each kind of grains forming the tile. Both should be useful to act over and control the manufacturing process. To accomplish this, we present an image processing method which is an improvement, based in adding the colour and mixing process information, to the well known 'Fuzzy C-Means' clustering algorithm. It is divided into two parts:

(1) The 'Fuzzy C-Means' algorithm itself, used in this case for colour segmentation of the grains; and
(2) A centres refinement process of the previous segmentation, allowing a more precise measurement of colour and grain proportion. This second part of the method is our proposal.

The paper is organized as follows: Section 2 describes the manufacturing process and states the necessity of controlling the parameters that are responsible of the colours and the proportions of grains in the tiles. Sections 3 and 4 focus on the first and second parts of the image processing method, respectively. Section 5 shows comparative results between the clustering and the centres refinement applied to through-body porcelain tiles. In Section 6 the feasibility of the proposed method application to other types of tiles is briefly commented on. Finally, Section 7 presents our conclusions.

2. Problem statement

The manufacturing process of through-body porcelain tiles consists of the following steps[1]:

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(1) Raw materials selection. Main components as kaolin and ball clays, feldspars and quartz sand are carefully selected to get highly homogeneous groups.
(2) Milling and spray drying. Raw materials are introduced in mills producing a suspension called slip. Slip is then spray dried to reduce its humidity to values around 5%. The output are the grains that will form the tiles. These are stored in different silos.
(3) Pressing and drying. Tiles are formed by uni-axial pressing of the grains mixture, usually at high pressures, 40–55 MPa. They are then dried to humidity values of 0.2–0.5%.
(4) Firing. The shaped tiles are fired inside an oven in cycles of 40–55 min at a maximum temperature of 1220 °C to acquire the desired physical properties.
(5) Polishing. Optionally, the surfaces of the fired tiles are polished, giving them a characteristic shine.

The objective of a production line is to manufacture tiles that keep uniformity in their visual aspect. To achieve this result the production is classified. Traditionally, this classification is done by means of an operator intervention, nevertheless the trend in last years is to automate this process.[2,3]

The other possible solution in order to achieve uniformity is stated as a hypothesis in this paper. We have made the assumption that visual appearance of through-body porcelain tiles depends on two factors: (1) the colour of each kind of grain; and (2) the proportion of each kind of grain. Hence, uncontrolled variations in the production process, such as temperature along different areas within the oven, the way of storing the grains in the silos, or the dosing and mixing processes, would be the causes of undesired variations in the visual appearance of the tile. These variations could be minimized by means of a control system, thereby achieving the objective of an homogeneous production. The system should act directly over certain parameters in the production process, depending on the feedback of the visual appearance of the tile. The feedback can be obtained with image acquisition and image processing techniques.

We expect this paper to contribute to the second of the mentioned solutions, describing an image processing method for the measurement of these two variables, grain colour and proportion. However, the manner in which the control system should act over the production process will not be tackled in this work.

3. Method

In this section, we explain the application of the clustering method, 'Fuzzy C-Means' for the colour segmentation of through-body porcelain tiles. From this segmentation, an estimation of the basic grain colours and proportions of the grains forming these tiles will be obtained. At the end of the section, we expose the limitations of this method in the measurement of these parameters.

Our starting point is a colour image of a tile. This image comprises of pixels described by their RGB (Red, Green and Blue) colour components. The colour segmentation is equivalent to classify each of the pixels in groups, according to their colour. The number of groups corresponds to the number of the original colours present. In this application, these colours coincide with the different kinds of grains forming the tile.

It is known that the RGB space is not the most suitable for colour segmentation.[4] This is due to two reasons: (1) the distances between colours in the RGB space do not correspond to their differences in their visual aspect, in other words, the RGB space is not perceptual; (2) the variables 'R', 'G' and 'B' are highly correlated, an undesired property for segmentation.

These disadvantages could be avoided by the use of a different colour space, as the CIE-Lab colour space. Formulas for conversion from RGB to Lab coordinates, and vice-versa, can be found in.[5] In Lab coordinates, human perception of colour difference corresponds with the euclidean difference, and the three components, 'L', 'a' and 'b' are decorrelated. Moreover, the colour information ('a' and 'b') is separated from the intensity ('L').

Colour segmentation will consist of classifying the histogram points into as many groups as distinct types of grains there are present in the tile. In the example of Fig. 1a, there are two. Nevertheless, as can be observed, there is no clear separation between the two groups; in fact, there is a continuous colour gamut between them. Therefore, the application of a fuzzy clustering method is convenient. It assigns each pixel the probabilities of belonging (degree of membership) to each of the clusters.[6]

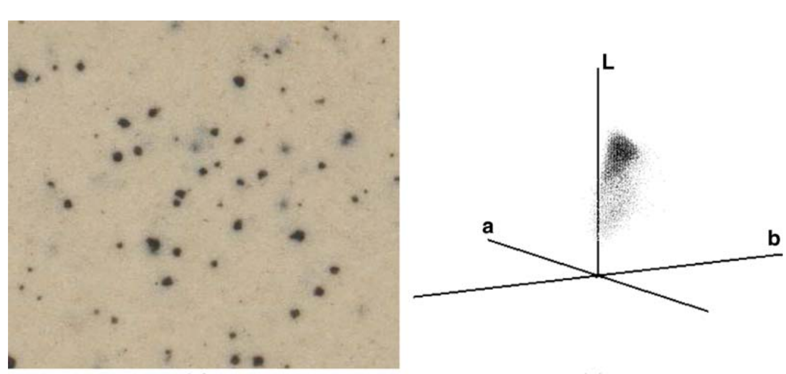


Fig. 1. (a) Sample of a 'Teide' model porcelain tile. (b) Colour histogram of the tile.

In this algorithm, the clusters are represented by their centres, which are the points that optimize the goal function:

$$j_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^m \|x_i - c_j\|^2 \tag{1}$$

where j_m is the value to minimize, x_i is each of the N pixels to group, c_j is the centre of each of the C clusters, u_{ij} is the probability that x_i belongs to c_j, and m ($m > 1$) is a real number that weights the degree of membership.

The symbols $\| * \|$ denote the function used to evaluate the difference between a point and the centre of a cluster. In this case, the point corresponds to the colour coordinates of a pixel, and the function of differences corresponds, as was mentioned before, to the euclidean distance. Hence, the colour difference between two pixels x_i and x_j with colour coordinates (l_i, a_i, b_i) and (l_j, a_j, b_j) is:

$$\|x_i - x_j\| = \sqrt{(l_j - l_i)^2 + (a_j - a_i)^2 + (b_j - b_i)^2} \tag{2}$$

The algorithm consists of successively approaching to the location of the optimum centres. It is an iterative process that follows the given steps:

(1) From the initial (user defined) centres, compute the membership matrix.
(2) Compute the new centres with the updated membership matrix.
(3) Update the membership matrix.
(4) Compute the error.
(5) If $error > \epsilon$ return to (2); else, finalize.

The membership degrees of all pixels against all centres are arranged into the membership matrix. Each element from this matrix, u_{ij} is computed according to the equation:

$$u_{ij} = \frac{1}{\sum_{k=1}^{C} (\|x_i - c_j\| / \|x_i - c_k\|)^{(2/(m-1))}} \tag{3}$$

where u_{ij} is the membership degree of point x_i to cluster c_j, and c_k is the centre of each of the C clusters.

From the membership matrix, the updated centres are computed according to:

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^m x_i}{\sum_{i=1}^{N} u_{ij}^m} \tag{4}$$

The error of each iteration loop is a distance, that measures the displacement of each updated centre with respect to its position in the previous iteration. The whole process ends when the maximum displacement is less than a user defined ϵ tolerance value.

In our case, given that many pixels from the image usually have the same colour, it is convenient to introduce the colour histogram in the former equations. In this manner, many repeated computations are avoided, thus meaningfully optimizing the computing time.

Hence, it is not necessary to compute the membership matrix for all pixels (Eq. (3)), rather, it is enough to compute it for the N' pixels with different colours y_i.

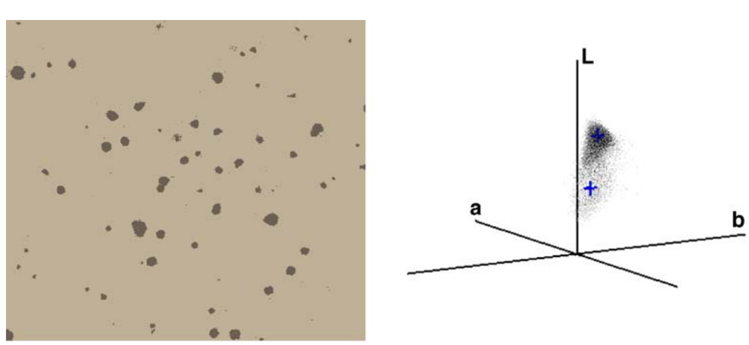
When computing the centres, introducing in Eq. (3) the number of occurrences of each colour y_i, $h[y_i]$, there is a noticeable reduction in the number of operations. The new formula is:

$$c_j = \frac{\sum_{i=1}^{N'} u_{ij}^m y_i h[y_i]}{\sum_{i=1}^{N'} u_{ij}^m h[y_i]} \tag{5}$$

where N' is the number of different colours present in the image.

The result of applying the 'Fuzzy C-Means' algorithm ($m = 2$) to the image in Fig. 1a is shown in Fig. 2. In Fig. 2a, the result of the segmentation is shown with the two obtained clusters, where each of them is represented by the colour of its centre. In Fig. 2b the centres of the computed clusters are shown, plotted on the colour histogram.

The centres of the clusters represent an approximation to the original colours of the two kinds of grains, which set up the first measured variable. The proportion of the grains, the second variable, could be obtained by counting the number of pixels belonging to each cluster, considering that each pixel is assigned to the one with highest membership degree.



(a) Colour Segmentation. (b) Histogram with the centres of the clusters plotted.

Fig. 2. Result of applying 'Fuzzy C-Means' algorithm for colour segmentation to a 'Teide' model porcelain tile sample.

Some deficiencies in the use of this method to our application can be noted. First, the centres of the clusters do not correspond to the original colours of the grains in the tile. The centre of the lighter cluster is darker than it should be, and vice-versa, the darker one is lighter than the original. This shift also affects the computation of the membership matrix, thus biasing the estimation of grains proportion. For this reason, a refinement of the centres computed with this method, that improves the estimation of the variables, is needed. This centres refinement is presented in next section.

4. Refinement

The reason why the centres of the clusters obtained by 'Fuzzy C-Means' segmentations do not coincide with the original grain colours is the presence of colour mixtures. Rather than having only the original colours present, there is a continuous gamut between them.

The causes of the appearance of this colour mixtures are found in the production process. One of the causes is the grain mixture by compacting. The other cause is their partial transparency, resulting in the grains in the interior layers to be partially visible on the surface.

In this section we briefly explain the theory of colour mixing. We go on to propose a correction to the former method, based on the inverse process of the mixing, from which we will obtain a more accurate approximation of the centres, and consequently, of the original colours of the tiles.

The colour mixing process can be graphically represented using the CIE (*Commission Internationale de l'Eclairage*) chromaticity diagram. Fig. 3a shows an example of mixing two colours. All the possible resulting colours are located over the rectilinear segment that joins them. Fig. 3b shows an example of mixing four colours. Similarly, all the possible resulting colours are included inside the convex polygon that joins them. The location of the obtained colour depends on the proportions of the basic colours. It will lie closer to the colours with higher amounts and vice versa.[5]

The centres refinement of the former method consists of shifting the centres of the clusters near to the boundaries of the rectilinear segment (for two colours), or the polygon vertices (for three or more colours). Therefore, the refined centre for each cluster would be that point x_i, that fulfil two conditions:

(i) (x_i) is grouped in cluster (c_j).
(ii) (x_i) maximizes the sum of distances to the rest of clusters:

$$d_{\text{clusters}} = \sum_{1 \le k \le C \wedge k \ne j} \|x_i - c_k\| \qquad (6)$$

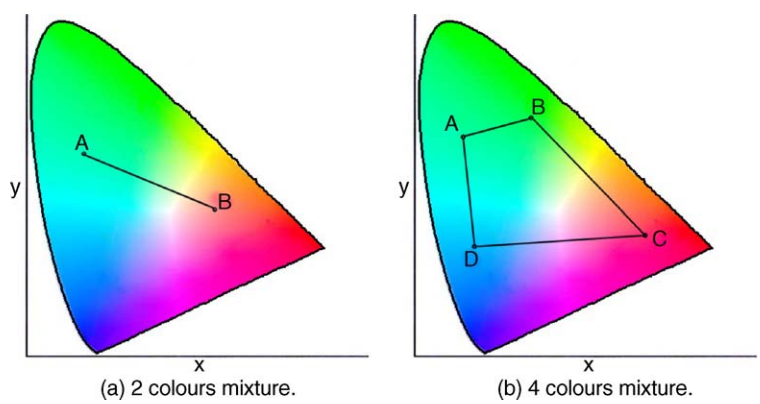


Fig. 3. Graphic representation of colours mixturing in the CIE chromaticity diagram. In (a), all the possible resulting colours from A and B are located over the rectilinear segment that joins them. Similarly, in (b), all the possible colours from A, B, C and D are located inside the convex polygon that joins them.

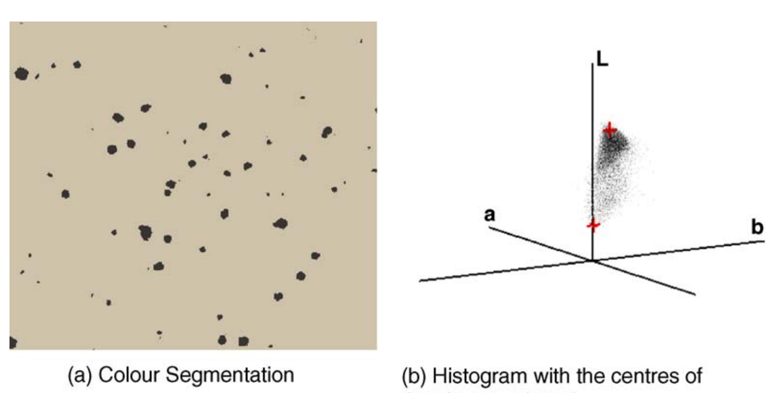
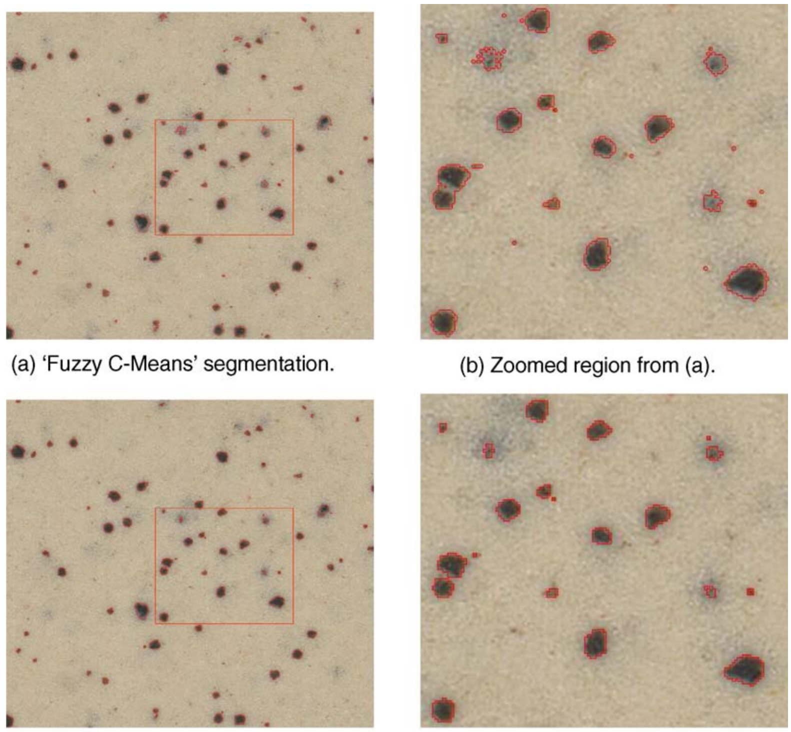


Fig. 4. Improvement in the measurement of the colours with the proposed centres refinement.



(a) 'Fuzzy C-Means' segmentation. (b) Zoomed region from (a).
(c) Segmentation after centres re-finement. (d) Zoomed region of (c).

Fig. 5. Improvement in the measurement of grain proportion with the proposed centres refinement.

We have experimentally observed that, in images from real porcelain tiles, it is not advisable to rely on the colour of a unique pixel that fulfils conditions (i) and (ii) to be the centre of the cluster. This is due to the presence of impurities in the tiles, that are not representative of the grain colours we want to estimate. Hence, the pixel x_i must be replaced in both conditions for a sufficient proportion of points from the cluster. This proportion should be high enough, such that the searched vertices are not confused with the impurities.

Fig. 4 shows the result of the application of this correction to the example of the Figs. 1 and 2. We can notice that the centres of the clusters obtained are a better approximation to the original grain colours. It is proven graphically by plotting the new centres in the histogram, and verifying that they are closer to the extremes of the gamut, as is shown in Fig. 4b.

With the better approximation of the original colours, we also get a more accurate measurement of the grain proportion. This is shown in Fig. 5, where the limits of dark grain areas are drawn in two cases: Fig. 5a and b present the regions obtained with the 'Fuzzy C-Means' method and Fig. 5c and d show the regions obtained with the proposed centres refinement.

5. Results

In this section, we present the results of applying the proposed method to both synthetic and captured images from real through-body porcelain tiles. The results of the two steps, the 'Fuzzy C-Means' clustering and the final segmentation with the centres refinement proposed by us, are shown for three experiments in Table 1. The processing times for the experiments carried out on real tiles are shown in Table 2.

The data presented in Table 1 correspond to: the original colours used for each of the three images, the approximation computed by the 'Fuzzy C-Means' algorithm, and the colours computed with centres refinement. It can be observed that the centres refinement gives more precise results.

Table 1
Original colours in the synthetic images, and the estimations from 'Fuzzy C-Means' algorithm and the centres refinement

Test number		Original colour	'Fuzzy C-Means' approximation	Centres refinement
1 'Synthetic'	C1	(200, 200, 160)	(171, 170, 136)	(199, 197, 158)
	C2	(60, 80, 50)	(74, 86, 59)	(60, 77, 48)
	C3	(40, 40, 40)	(54, 55, 49)	(39, 39, 39)
3 'Tarifa'	C1	(191, 172, 143)	(170, 155, 132)	(188, 170, 141)
	C2	(78, 96, 122)	(91, 100, 115)	(77, 95,119)
	C3	(106, 90, 68)	(108, 96, 80)	(104, 89, 68)
2 'Granada'	C1	(134, 134, 122)	(128, 122, 111)	(134, 131, 120)
	C2	(174, 136, 121)	(156, 123, 113)	(172, 134, 120)
	C3	(40, 40, 40)	(60, 57, 54)	(40, 40, 40)

Table 2
Execution time (ms) of the test

Process	Tile model		
	'Teide'	'Tarifa'	'Granada'
Processor: Pentium IV @ 3.06 GHz			
Lab histogram	275	243	148
Fuzzy C-Means	11	17	16
Centres refinement	75	122	92
Pixel classification	11	14	14
Total (ms)	372	396	270

The three experiments are the following:

Test 1. A synthetic image was created simulating a mixture of three different colours. The proportion of each original colour in a pixel of the resulting image was randomly computed.

Tests 2 and 3. Both experiments were carried out with real tiles. The models called 'Tarifa' and 'Granada' were used in Tests 2 and 3, respectively. The images were obtained using an off the shelf scanner, with the following specifications: RGB colour with 8 bits per component, spatial resolution of 600 dots per inch (23.6 pixels/mm) and a size of 386 × 344 pixels.

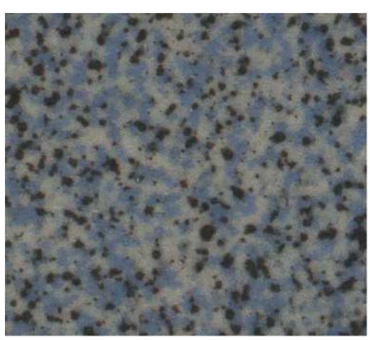
Fig. 6a shows the tile model 'Tarifa', formed by three kinds of grains: light, dark and blue-coloured. Fig. 6b shows the result of the segmentation with the 'Fuzzy C-Means' algorithm, whereas Fig. 6c shows the segmentation with the proposed centres refinement. It is evident that the colours obtained in the second case are purer and much more similar to the original colours than the ones obtained with the 'Fuzzy C-Means' algorithm. The centres obtained from both operations are plotted on the histogram in Fig. 6d. 'Fuzzy C-Means' centres are plotted in blue and the refined centres in red. As it was expected, the blue centres are located in the boundaries of the histogram.

The same data are presented for the 'Granada' model tile. This tile is also formed by three kinds of grains: light, dark and red-coloured. The results are arranged in the same manner as before in Fig. 7a–d. In this case, the improvement in the original colours approximation with the centres refinement is even more evident.

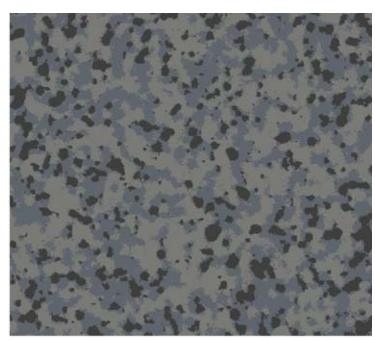
This improvement in the original colours computation results in a better estimation of the grains proportion, as has been experimentally proven in the previous section.

The execution times of the processes are detailed in Table 2. Computing times for the Lab Histogram calculation are higher for the 'Tarifa' and 'Teide' models as compared to times for the 'Granada' model. This is due to the greater number of colours present in the first two in comparison to the third. The colours counted in the images were: 16,878 for 'Tarifa', 19,097 for 'Teide' and 8634 for 'Granada'. The time consumed in the rest of the process is lower in the 'Teide' model because it has only two original colours, whereas the 'Tarifa' and 'Granada' models use three.

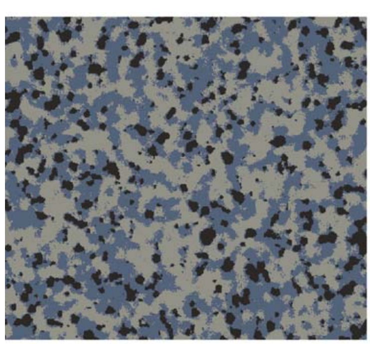
Though the analysed zone in the provided examples does not cover the complete tile, it can be considered as a sufficient rep-



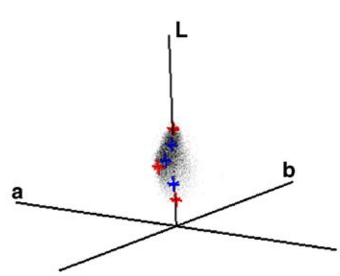
(a) 'Tarifa' model tile sample.



(b) Clusters computed with 'Fuzzy C-Means'.

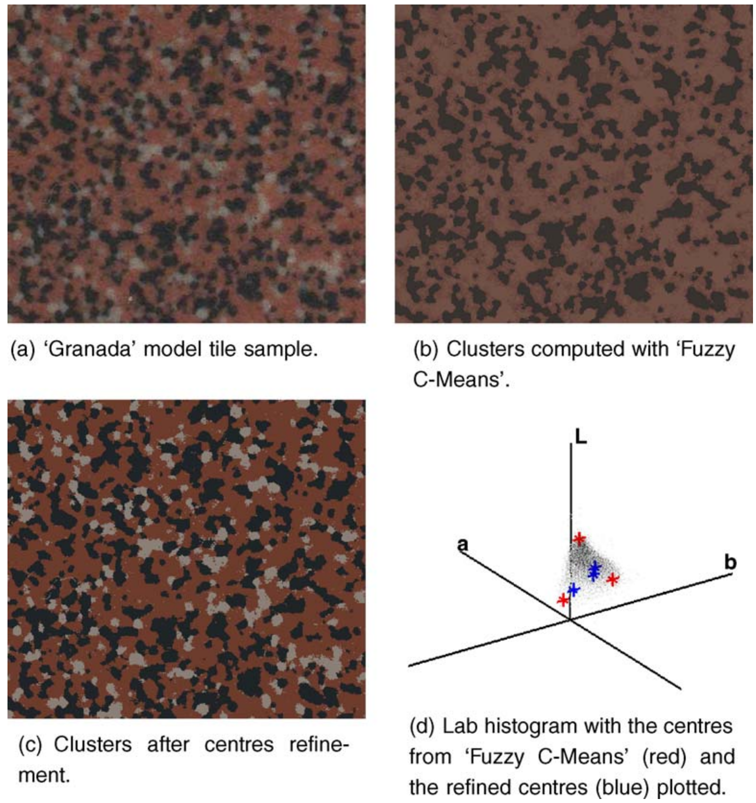


(c) Clusters after centres refinement.



(d) Lab histogram with the centres from 'Fuzzy C-Means' (red) and the refined centres (blue) plotted.

Fig. 6. Obtained results after applying the method to a 'Tarifa' model tile sample.



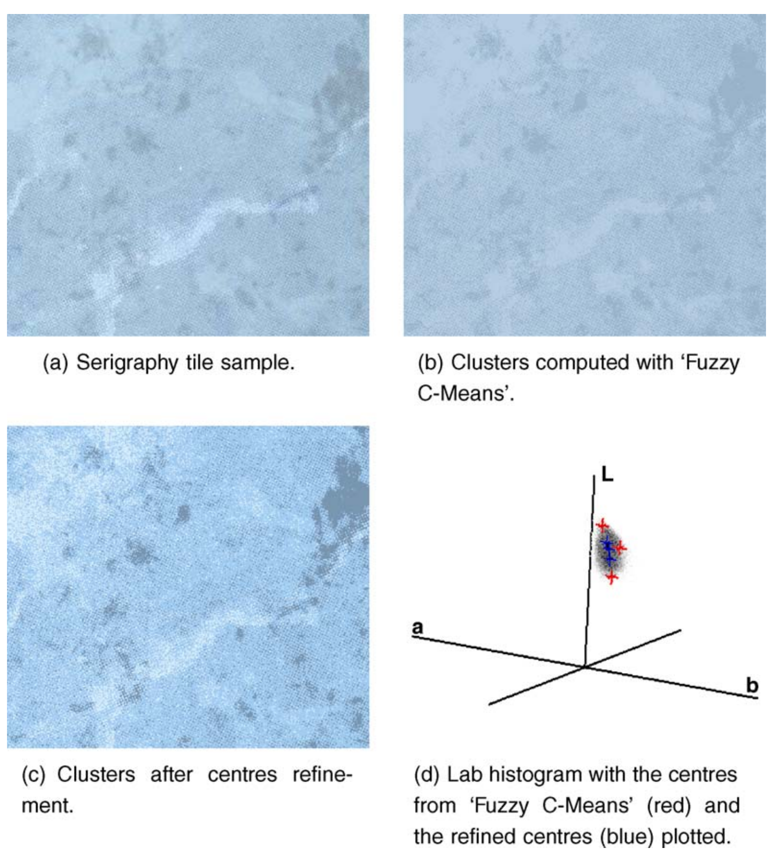
(a) 'Granada' model tile sample.

(b) Clusters computed with 'Fuzzy C-Means'.

(c) Clusters after centres refinement.

(d) Lab histogram with the centres from 'Fuzzy C-Means' (red) and the refined centres (blue) plotted.

Fig. 7. Lab histogram with the centres from 'Fuzzy C-Means' (red) and the refined centres (blue) plotted.



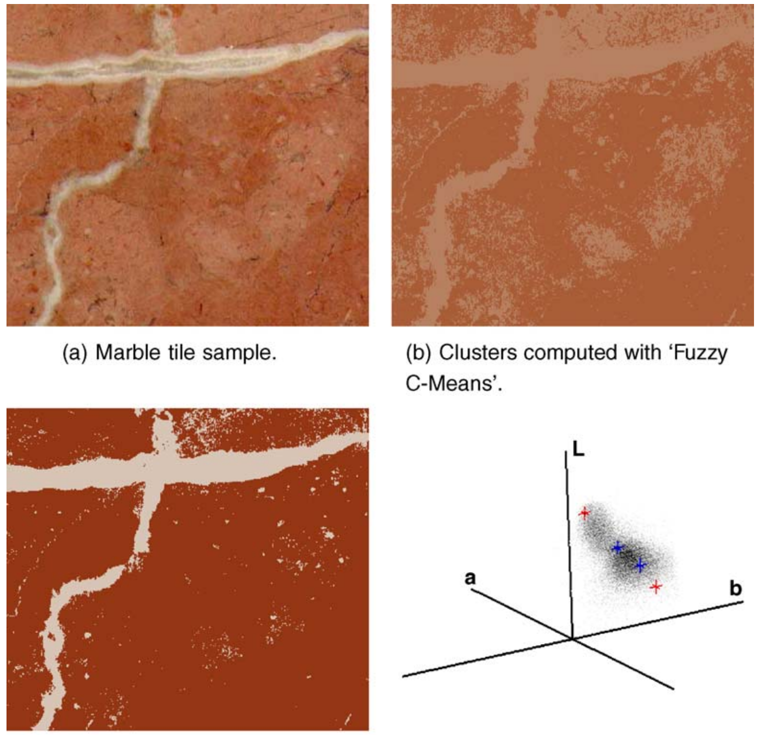
(a) Serigraphy tile sample.

(b) Clusters computed with 'Fuzzy C-Means'.

(c) Clusters after centres refinement.

(d) Lab histogram with the centres from 'Fuzzy C-Means' (red) and the refined centres (blue) plotted.

Fig. 8. Obtained results after applying the method to a serigraphy tile sample.



(a) Marble tile sample.

(b) Clusters computed with 'Fuzzy C-Means'.

(c) Clusters after centres refinement.

(d) Lab histogram with the centres from 'Fuzzy C-Means' (red) and the refined centres (blue) plotted.

Fig. 9. Obtained results after applying the method to a marble tile sample.

resentative part. Considering this condition, we can say that the presented method is valid for the on-line control of a production line.

6. Other applications

Even though the proposed method has been specifically developed for through-body porcelain tiles, its applications could be extended to other types of tiles. This possibility is shown in the next two examples.

In Fig. 8, the results from a silk screen process or serigraphy tile sample are presented. The fabrication process includes three colouring stages. In each stage, a different colouring ink is applied. It is evident that the refined centres are a closer approximation to the original tones of the inks, than the ones obtained with 'Fuzzy C-Means'. This measurement could be used to control the production process if any deviation in the inks is detected.

In the same manner, Fig. 9 shows the results for a marble tile sample. In this case, each centre represent the original colour of one of the two majority natural components of this kind of marble.

7. Conclusions

We have presented an image processing method that can be applied as a feedback step in the manufacturing process of through-body porcelain tiles. This feedback contributes to achieve a uniform visual appearance of the products.

The method consists of the measurement of colour and proportion of grains in the tiles. It has been divided in two parts, the second of which was proposed by us. The first corresponds to a colour segmentation using the 'Fuzzy C-means' algorithm, whereas the second corresponds to a centres refinement of the obtained clusters. The refinement is based on the colour information and the colour mixing process.

The experimental results prove that the method is reliable for the calculation of both variables, the colour and the proportion of the grains. In addition, the processing times show that it would be viable to execute in real time on a production line.

Finally, it has been proven that the proposed method could be applied to other types of tiles.

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