Letters to the Editor

Automatic Color Grading of Ceramic Tiles Using Machine Vision

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***Abstract*— We present a method designed to solve the problem of automatic color grading for industrial inspection of plain and patterned ceramic tiles. We discuss problems we were confronted with, like the temporal and spatial variation of the illumination, and the ways we dealt with them. Then, we present results of correctly grading a series of ceramic tiles, the differences of which were at the threshold of human perception.**

***Index Terms*—Ceramics industry, color measurement, inspection.**

I. Introduction

This paper is concerned with the problem of automatic color shade grading of plain and patterned ceramic tiles using machine vision. We first tackle the problem of color shade grading of uniformly colored tiles, and then we proceed to the case of two-colored tiles. For more details of our approach, see [1] and [2].

The major difficulty one has to overcome is posed by the image acquisition procedure. In order to be able to perform color inspection, and in particular to grade colors, we need to create image acquisition conditions which have the following properties: spatial constancy, temporal constancy, and high signal to noise ratio.

When one works at the threshold of human color variability perception, the difference between the various color grades is of the order of 1 or less grey value in each spectral component, out of a full range of 256. In any case, the whole range of shades covers only an extremely small volume in the RGB space, which seldomly exceeds a sphere of 3 grey level radius. Even in low noise conditions, the classification problem involved in grading is faced with signal to noise ratios of 1:10. Additional difficulties are posed by the limited dynamic range of the camera system and nonlinearities in the image acquisition chain.

II. Image Acquisition

For our experiments, we used a high precision RGB camera,[1] connected to an 8-b frame grabber,[2] which provided images with reasonable noise level.

The sequence we followed in order to capture the test images is as follows. After setting up the environment, we grab a set of images of the same tile, from which we shall determine the temporal behavior of the illumination. These images may not be grabbed one after the other, but with an interval (e.g., 1 or 2 min) in between. We chose to have 20 images in each set [see Fig. 1(a)]. Then we grab another set of images, to determine the spatial behavior of the illumination. Ideally, this behavior could be determined using only one surface of absolutely uniform reflectance. For practical reasons, we decided to use a plain tile, which is nearly uniform. The tile was imaged in four rotated positions and the illumination fields calculated from each position were averaged to eliminate any influence from irregularities that the tile might have. Then, we grab the tiles that we want to color grade. The consistency of our method between different experiments, repeated using different setups of the camera and the illumination, proved to be very good.

III. Illumination Corrections

In most of the images that we grabbed, the spatial variation of the illumination over a tile can be well approximated by a second order two-dimensional polynomial [see Fig. 1(b)]. The coefficients of this polynomial are computed using least square error fitting. We perform three fittings, one for every chromatic component, and we obtain three different sets of polynomial coefficients. After calculating the coefficients for every image of a given training set, a new set of coefficients is calculated by taking the averages of the corresponding coefficients for the images in the set. Hence, the more training images, the more accurate the modeling of the illumination will be.

From the sequence of 20 images we captured initially, we get a set of points (I_R, I_T) that represent the mean intensities of the reference surface and the tile, respectively. Although the response of the camera-grabber combination is known to be nonlinear, for a limited subset of the grey-level space we can assume that it is linear. Indeed, all the data points (I_R, I_T) are restricted to an area of about eight grey levels. So, the relation between the intensity change of the tile and the reference surface can be locally described by a linear function. The slope a of this function is computed using least square error fitting.

Since the response of the sensor is only locally linear, for each category of tiles we must compute a separately. This is demonstrated by Fig. 1(c) and (d), where one can see that entirely different lines fit two different categories of tiles, one dark and one bright.

The slope a determines the ratio of a small difference in the I value of the tile over a small difference in the I value of the reference surface:

$$a = \frac{\Delta I_{\text{Tile}}}{\Delta I_{\text{Ref}}} = \frac{I_{\text{Tile}_{\text{measured}}} - I_{\text{Tile}_{\text{corrected}}}}{I_{\text{Ref}_{\text{measured}}} - I_{\text{Ref}_0}}. \quad (1)$$

We choose to refer all the tile intensities to the same intensity of the reference surface which we call I_{Ref_0}. This reference point is

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[1] JVC Service Manual, Color Video Camera TK-1270, Apr. 1994.

[2] A65/A66 Installation Manual, Manual Part Number: 9100-0174-00, Feb. 1993.

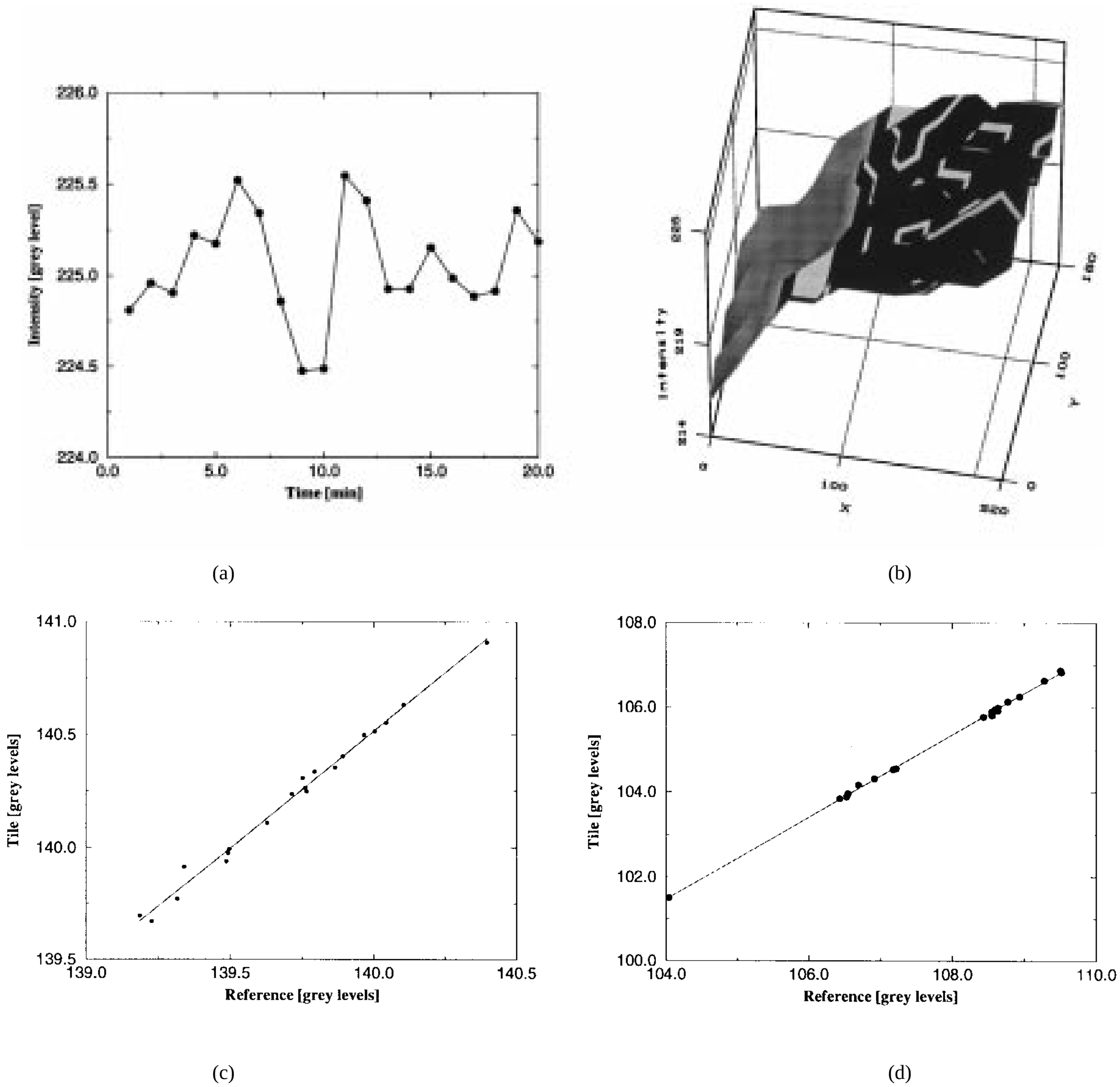

Fig. 1. (a) The average intensity of the images of a uniform colored tile captured one after the other with no change in the grabbing setup,.(b) The gray level values of an image of a plain tile, demonstrating the spatial variation of the illumination. (c) Linear regression for temporal correction of blue tiles. (d) Linear regression for temporal correction of white tiles.

chosen to be the average of all intensities calculated for the reference tile from the 20 images used to compute a. In the above discussion, I stands for the R, G, or B component.

Notice that the temporal correction takes place after the spatial correction, hence, it is applied to the spatially corrected versions of the images.

IV. Experiments

For our experiments, we selected various sets of plain tiles. Each category was shade graded by human experts. The experiments for each category of tiles were repeated several times to evaluate the consistency of the image acquisition environment, using different viewing and illumination conditions every time.

Fig. 2(a) and (b) illustrate the grading of one set of tiles, before applying any corrections to the data. Fig. 2(a) plots the grading for one of the RGB channels, whereas Fig. 2(b) plots the grading in the three-dimensional RGB space. Tiles that belong to the same category, according to the human experts, are represented by the same symbol. From these results, it is clear that it is not possible to color grade these tiles without any preprocessing.

Fig. 2(c) and (d) illustrate the grading of the same plain tiles after applying the spatial and temporal corrections to the data. In this case, one can clearly see three clusters of tiles, representing the three color grades.

V. Two-Colored Tiles

One major difficulty with the two-colored tiles was the grabbing of the images. Since now the tiles may contain areas of contrasting intensities (i.e., very dark and very bright), it is not possible to set up our camera gain so that the average of the image lies in the linear part of its response. Either the bright areas or the dark areas would be saturated. Thus, for each tile we had to grab two images, one with camera setting appropriate for bright colors and another for dark colors.

Further, we cannot use a bright reference surface when grabbing with settings for the dark areas of the tile, and vice versa. So, we

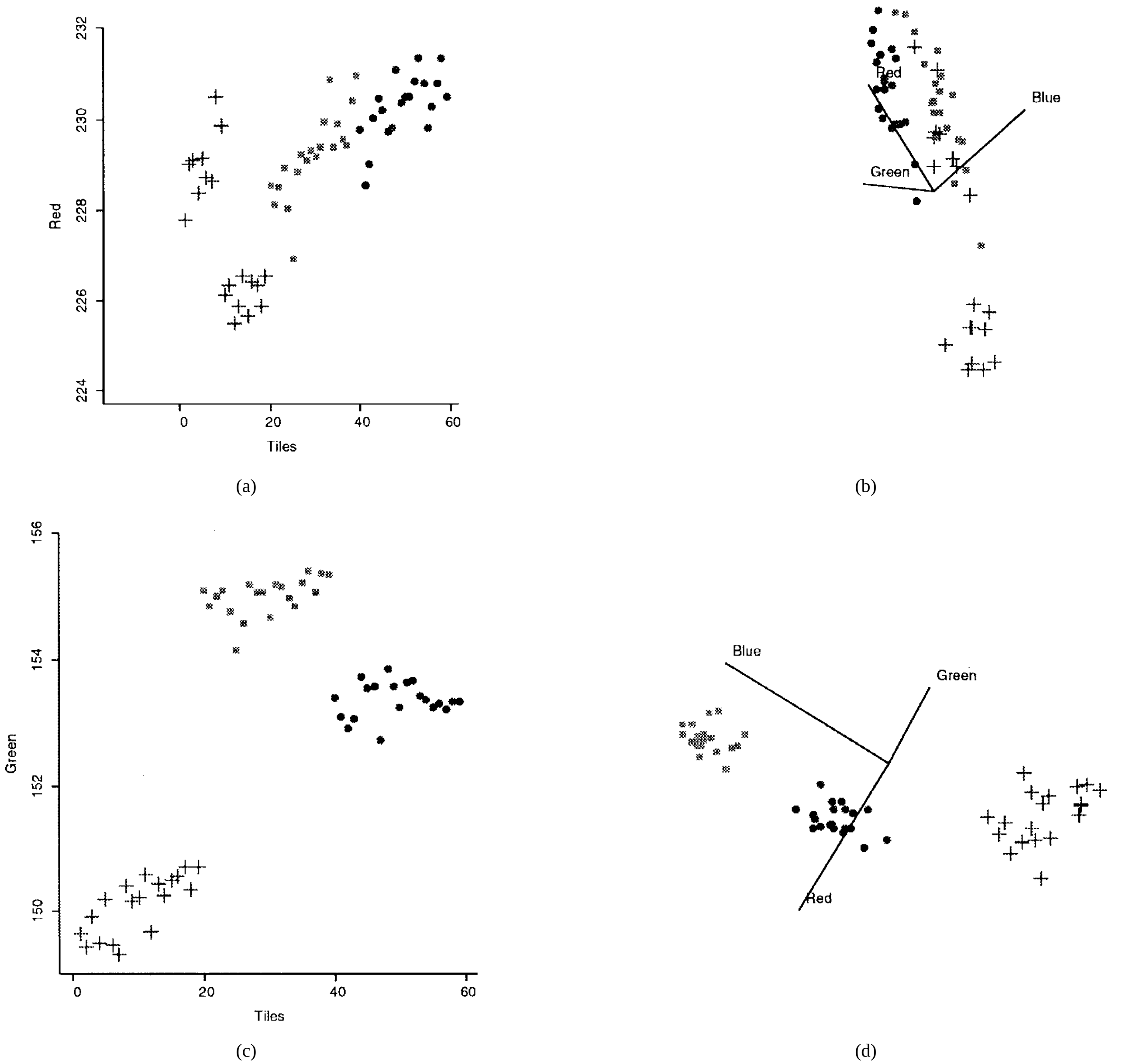

Fig. 2. Color grading before and after the illumination corrections. (a) 2D. (b) 3D. (c) 2D. (d) 3D.

decided to use, for every set of images, a different reference surface with intensity similar to that of the area of interest, which was chosen to be a properly colored plain tile.

As far as the data for spatial correction is concerned, we used plain tiles to determine the spatial constancy of the illumination field. We cannot do this using a patterned tile, because the reflectivity of the tile itself has spatial variation due to the printed pattern on it.

In order to color grade the tiles then, we treat each area separately, as if it were a plain tile. Therefore, accurate segmentation into the two chromatic classes is critical, since errors in this stage propagate to later phases. We used the K-Means algorithm, with the clustering taking place in the RGB color space. After segmenting the images, we process only pixels that belong to the appropriate chromatic area under consideration. This means that for tiles with very fine texture, the images for the foreground may be quite sparse.

Fig. 3(a)–(d) demonstrates the results of our method for the foreground and the background of two different categories of patterned tiles. Each category was graded in two sets of six tiles, with inter-class difference of about three grey levels only.

Fig. 3(a) and (b) refers to a set of tiles with a well-defined pattern that consists of thick lines and patches. We can see that the difference between the two classes of the tiles manifests itself both in the foreground and the background mean color values computed. In Fig. 3(c) and (d), we present the results concerning a set of tiles with a very intricate pattern that consists of very thin lines. The two lots of tiles are easily separated by our system on the basis of the background pixels, in agreement with the human classification, as shown in Fig. 3(d). In Fig. 3(c), however, where we plot the values calculated from the foreground pixels only, the two classes cannot be discriminated by our system. The interesting thing is that the humans cannot distinguish the two classes, either, on the basis of the pattern only. The two different symbols we use in Fig. 3(c) are used to identify the two gradings performed by humans on the basis of the background pixels only, not the foreground. We attribute this to

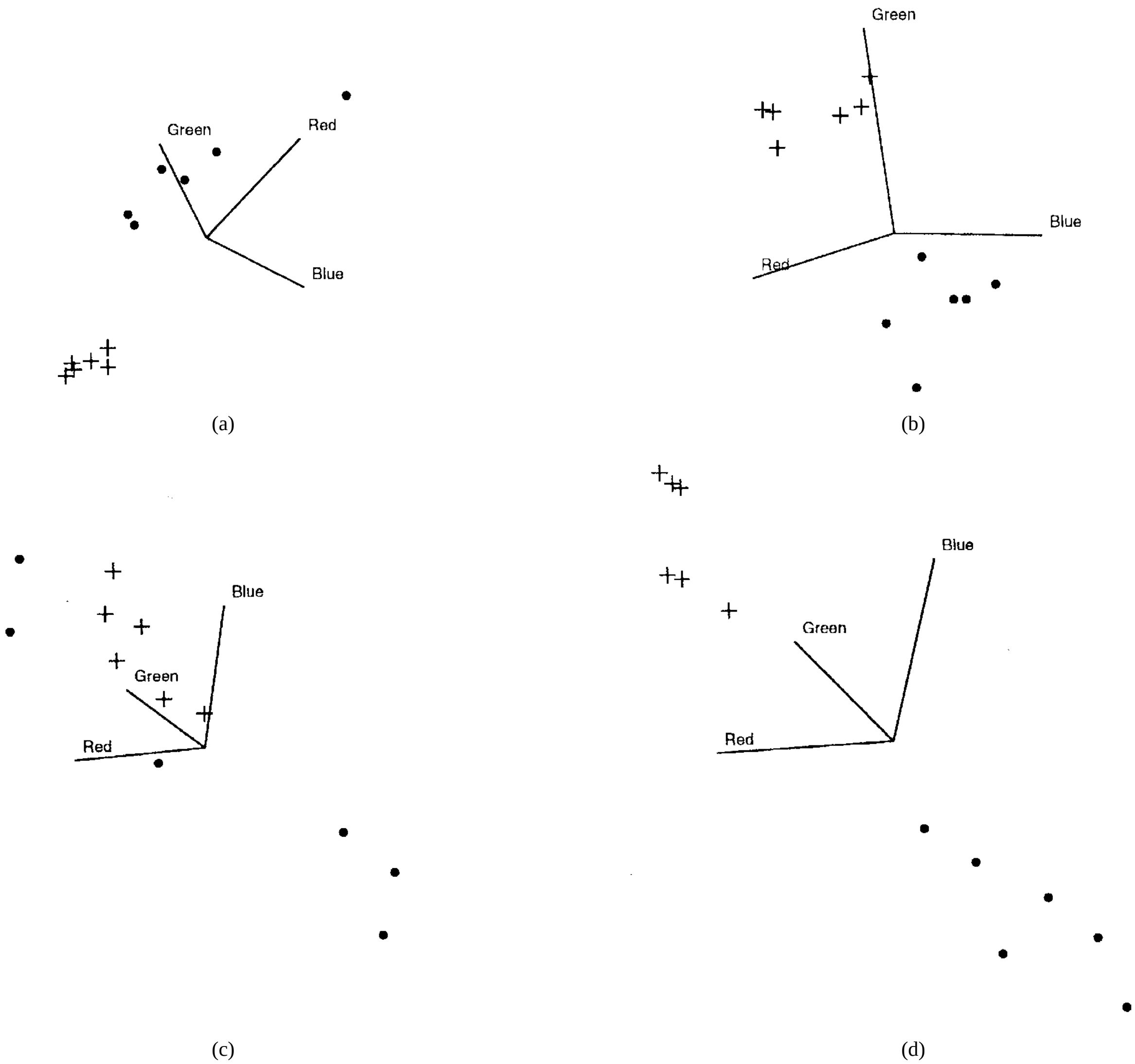

Fig. 3. Color grading of two-colored tiles. (a) Foreground. (b) Background. (c) Foreground. (d) Background.

the point spread function of both imaging systems—camera and eye. In both cases, during the process of imaging, some blurring takes place which reduces the color resolution of the system. Thus, the ability of discriminating subtle shades of color reduces as the patch of a uniformly colored area decreases significantly.

VI. Conclusions

A method for automatic grading of plain ceramic tiles according to color shade has been developed. It was found that in order to achieve the required accuracy, we had to apply corrections to the data to compensate for both spatial and temporal nonconstancies of the illumination.

For the case of two-colored patterned tiles, the necessity of developing linear cameras and sensors became apparent, but we managed to overcome this by taking multiple images of the same tile, using the optimal setup for every range of tile intensity values that can be fitted within the range of linear response of the camera. The results indicate that very thin patterns may not affect the color shade grading and can, therefore, be ignored, whereas the solid patterns must be graded.

The automatic inspection procedure has been tested on a number of tiles. The initial results confirm that the performance of the system corresponds to the predicted rates and the level of agreement with the subjective color shade categorization suggests that the developed solution can provide a basis for a viable commercial visual inspection system.

References

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[2] C. Boukouvalas, J. Kittler, R. Marik, M. Mirmehdi, and M. Petrou, "Ceramic tile inspection for colour and structural defects," in *Proc. AMPT95*, Ireland, 1995, pp. 390–399.