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Automatic Detection of Defects in Ornamental Limestone Using Wavelets

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***Abstract*—**A methodology based on wavelets is proposed for the automatic location and delimitation of defects in limestone plates. Natural defects include dark colored spots, crystal zones trapped in the stone, areas of abnormal contrast colors, cracks or fracture lines, and fossil patterns. Although some of these may or may not be considered as defects according to the intended use of the plate, the goal is to pair each stone with a map of defects that can be overlaid on a computer display. These layers of defects constitute a database that will allow the preliminary selection of matching tiles of a particular variety, with specific dimensions, for a requirement of N square meters, to be done on a desktop computer rather than by a two-hour search in the storage park, with human operators manipulating stone plates as large as 3 m x 2 m, weighing about one ton. Accident risks and work times are reduced, with a consequent increase in productivity. The base for the algorithm is wavelet decomposition executed in two instances of the original image, to detect both hypotheses – dark and clear defects. The existence and/or size of these defects are the gauge to classify the quality grade of the stone products. The tuning of parameters that are possible in the framework of the wavelets corresponds to different levels of accuracy in the drawing of the contours and selection of the defects size, which allows for the use of the map of defects to cut a selected stone into tiles with minimum waste, according the dimension of defects allowed.

***Keywords*—**Automatic detection, wavelets, defects, fracture lines.

I. Introduction

THE stone industry is represented in Portugal by 2,500 companies employing nearly 25,000 people to explore and transform natural stones for national and international markets, with Portugal occupying eighth place among producers and exploiters of ornamental stones around the world [1]. After the large blocks of rock have been sawed and the stone plates are polished and ready to be cut, a human operator localizes defective areas and places the required pieces of variable dimensions in the plate, in order to avoid waste.

Despite some of the defects being easily observed, the human factor introduces highly subjective constraints. Defects can be inclusions of materials different from the stone itself, e.g. crystalized minerals or strong gradients of color that may be very difficult to classify objectively.

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Due to the already referred relevance of this economic sector of industrial activity, some automation for the quality control process in line with other mechanical processing activities over the production line of the stone plates became an important and challenging topic for applied research, as happens in other industries [2], [3]. Pattern recognition [4] is not an alternative, due to the unexpected variety of defects.

Considering the final application of the processed materials and the fact that in the industry several quality grades of the plates are allowed corresponding to different economic values of the stones only reinforce the subjectivity included in the criteria used by the sequence of humans intervening in the production line [5].

The challenge is mainly due to the subjective character of the manual procedure and the different final applications of the processed materials, which must lead to different approaches.

As the requirements of each command are different according to the application to be done of the stone, the definition of "defect" is not constant - a previous choice will save time and money, as well as introduce some objectivity in an otherwise very subjective procedure.

The slabs of the data set came from large blocks of limestone, a sedimentary stone made up of calcium carbonate/calcite minerals. It is formed on the ocean floor when marine organisms extract calcium carbonate from sea water and from coral, shells and skeletons; as the structures accumulate on the ocean floor they become consolidated to form limestone. This is why we often find evidence of shells and fossils in limestone.

Limestone is widely used in commercial and residential applications including interior and exterior walls, flooring, countertops, entries, bathrooms and tabletops.

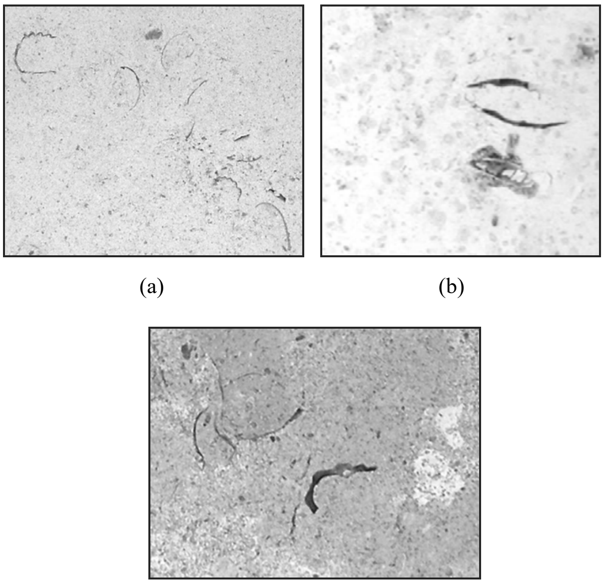
Due to the nature of the problem, the use of image processing techniques was the obvious choice together with the use of high resolution color cameras to acquire the images of the plate's surfaces in the production line.

In this paper, an automatic detector of major defective areas is described, which allows for a first stage of computer aided choice of the stone plates on a desktop computer. It was designed to account for local color variations, inclusions and intrusive accessory minerals [6], [7], but not micro-discontinuities, nor textural characteristics; with the image resolution and methodology chosen, defects smaller than 5 mm are out of reach.

II. Methodology and Discussion

The rationale exploited for the implementation is based on the fact that a defective area always presents a high degree of local contrast. Common defects found on stone blocks include patches or blotches, which are mineral deposits that may or may not be the same color as the surrounding stone; bands that run along the surface of the slabs, generally in a different tone; lines that can be fractures or thin inclusions of other materials; non-uniformity of color in the block that will make certain slabs appear less homogeneous or clearly two-toned; pattern variations that can have inclusions or just be a volume with different grain structure.

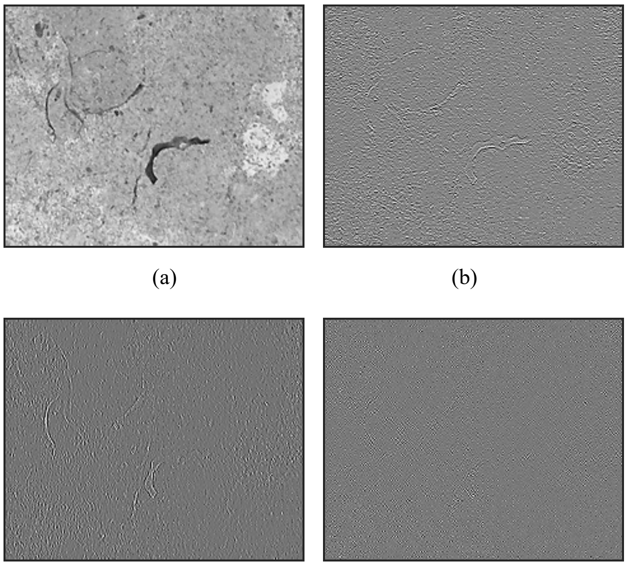
The main problem is defect variety, homogeneity clearer or darker than surrounding area, non-homogeneities with both possibilities included, or local color saturations. Concerning shape, the defects can be clearly linear or formed by an area of any shape, with a variable degree of filling (Fig. 1). In general, all defects are *local* manifestations – a spatial filter which could work locally ideally could isolate these areas, at least if the background had some degree of homogeneity, which is not the case for a large majority of limestone varieties: the background can have a "grain" of variable dimensions or be almost homogeneous, and as always, a large contrast range - such variety excludes common segmentation solutions [8], [9].



(a) (b) (c)

Fig. 1 Limestone typical defects: a) long linear defects in a small-grain stone, b) inclusions of variable shape, with different degree of filling, eventually rests of fossilized shells, and c) defective areas dark and clear, with various shapes - nearly linear and spot-like

The multiresolution ability of wavelets can be used to extract a feature from its background, in a scale related to the target dimensions, as each step (or level) in wavelet decomposition leads to an approximation at half resolution of the precedent, and a set of three corresponding sub-bands [10]. In each sub-band, which is the result of a particular combination of the filters, an image direction is enhanced, and the resulting sub-image is usually named after that direction: details (or sub-bands) horizontal, vertical and diagonal (Fig. 2).



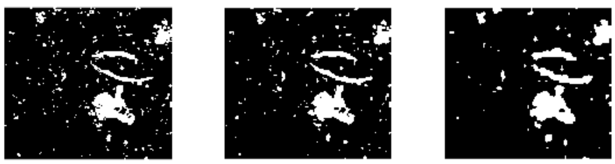
(a) (b) (c) (d)

Fig. 2 One level of wavelet decomposition: the initial image (Fig. 1 (c)), is decomposed in four signals: (a) an approximation at half resolution and three signals corresponding to (b) horizontal, (c) vertical and (d) diagonal sub-bands, where the enhancement of each direction is clearly visible

The features isolated in the details at each decomposition level are related to the initial and final scale for that level; the suppression of the details in the reconstruction phase makes it possible to keep only the structures that, by its dimensions, still subsist after N steps of decomposition (Fig. 3), whatever its shape.

The sequence of the procedure decomposition/ reconstruction repeated N times with the same wavelet leads to a simplification of the form, rather obvious when N=3, which implies 3 levels of signal decimation.

The last level of decomposition determines the objects surviving, but it is the intersection of all the masks that ensures a more precise form.



(a) (b) (c)

Fig. 3 Reconstruction of the binary mask corresponding to the image in Fig. 1 (b), from N successive levels of decomposition in wavelets using a truncated reconstruction process: a) N=1, b) N=2, c) N=3.

The algorithm developed for the limestone can use any level of decomposition and reconstruction, and any user-defined wavelet. A trade-off between the ideal ranges of targets to capture determines the appropriate final level of decomposition.

When a final work mask is found by intersection of all the intermediary masks, each object present in that mask is extracted from the original image and the average of the corresponding intensities is compared against the mean value of the image. Bright defective areas should have a mean value well above the average computed over all the pixels in the image to be accepted as white defects.

A last depuration consists in retain only objects of size larger than 80 pixels, because at this resolution smaller areas are not important for visual impact, and the most important criterion in regard to ornamental stones is the visual appearance.

To take account of both dark and clear defective areas that can be present simultaneously, as is the case in the stone shown in Fig. 1 (c), a second work version of the initial image is prepared complementing the original image; this one will enhance the dark defective areas. The same procedure is applied, but at the point of selection of the objects found, it is the standard deviation of the set of pixels corresponding to each object that is now compared to the standard deviation of the initial image. Being a local anomaly, the defect area should have a stronger variance of intensities than the overall image.

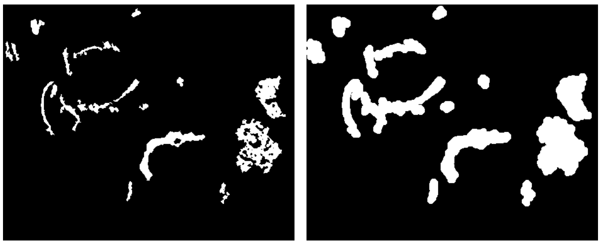
Two logical masks are obtained, one concerning the whitish inclusions, the other with the darkest defective areas (Fig. 4); the former are less frequent in the data set.

(a) (b)

Fig. 4 Masks of the dark (a) and clear (b) defects corresponding to the two work images based in the initial image in Fig. 1 (c) after general clean-up operations: only objects bigger than K pixels survive a morphological "open" operation

The two masks are cleaned up with morphological operations to discard small spots of pixels which are not relevant as defects for the stone exploitation. This is achieved using the dimension of the interesting spot as the size of the structuring element, with a morphological operation known as "open". The morphological open consists a sequence of two filters [11]: first, an erosion of the objects is performed with a structuring element [12], like a disk or a square, with the dimensions required, followed by dilation with the same structuring element. The practical result is that anything smaller than the structuring element chosen will disappear [13].

The white and dark binary masks are logically added in one final defects mask, to which operations of "fill" and "dilation" [14] are applied, in order to produce solid objects, one object per defect (Fig. 5). The "fill" function performs a filling of any hole inside the objects, while the "dilation" by a disk (of radius 10 pixel in this case) will enlarge the objects of interest (OoI). The goal of this set of OoI is to evaluate in the original image the degree of confidence offered by each object in the mask – the probability that it actually corresponds to a defective area. This last validation involves statistical measures and texture indicators that are compared with those of the initial image.



(a) (b)

Fig. 5 Final morphological operations: a) mask sum of both logical images corresponding to clear and dark defects (separated in Fig. 4); b) objects have holes filled in and are enlarged by a dilation operation in order to produce a contour to encompass each area of interest

The reunion of the two binary masks containing the objects validate as defects (Fig. 5) is a final mask with the location of all the areas that should not be included in any mosaic, whose contours can be overlaid in the original image (Fig. 6) as guidelines for the cutting session.

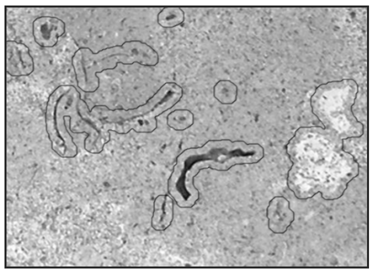


Fig. 6 Initial image with linear and spot-like, dark and clear defects localized by the methodology presented.

The algorithm implemented is schematized in Fig. 7. The block identified as "Wavelet spike filter" does not belong to the Matlab environment used for the implementation: it is a function developed for this effect that uses the basic routines in the wavelet toolbox.

Basically, it will decompose the work image with a user defined wavelet until a pre-defined level N, and proceed to the reconstruction of the signal from the approximation of order N, with the details suppressed (explicitly equal to zero). Depending on the level attained in the decomposition, some objects of smaller dimensions will not be present in the image reconstructed (Fig. 3).

Concerning the choice of the wavelet, the nearly symmetrical wavelets with compact support of the symlets family [15] are an interesting choice for the kind of defects presented in a selection of 55 large plates of limestone available as the test data set, as well as the more symmetric Daubechies wavelet [16].

The appropriate choice of the wavelet and level of decomposition are clearly dependent of the nature of the stone; a much textured stone will demand a deeper decomposition, whereas the extraction of defects from a smooth background will be successful with two levels of decomposition. This can be included in the algorithm using an entropy indicator [17] to decide the level of decomposition.

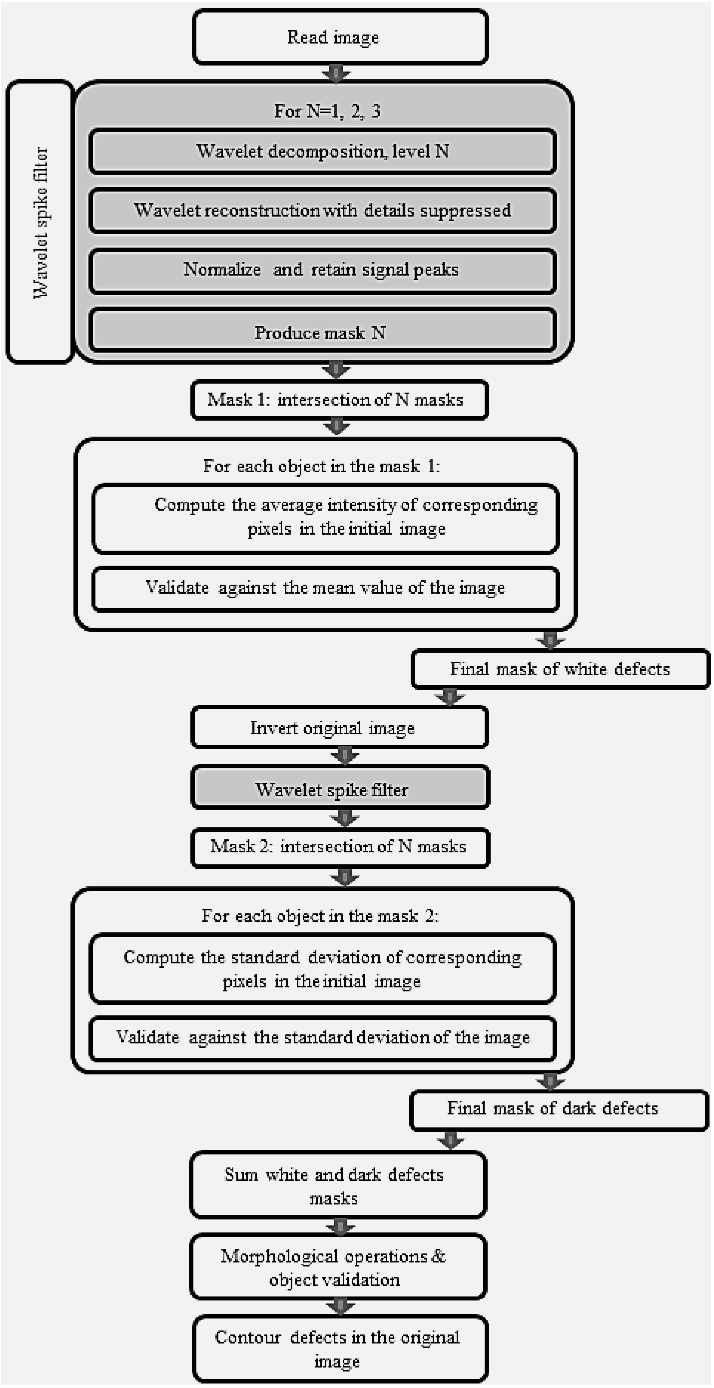


Fig. 7 Algorithm schematic sequence

The algorithm was tested in a large data set where almost all stone plates presented any kind of defective areas and the results correspond to the subjective preference of the persons in charge of this service. The need for human intervention is now limited to accepting or eliminating the defective areas automatically defined according to the end use of the stone, e.g. mosaics for the wall of a hall in a banking institution have different kinds of quality requests than those used for the pavement in a public outdoor area [18].

The results with near-linear inclusions, as those present in the test image in Fig. 1 (a), are shown in Fig. 8. The tolerance to the size of the spots included/excluded as defects is a parameter that can be implemented as user-defined, if a trained operator is available.

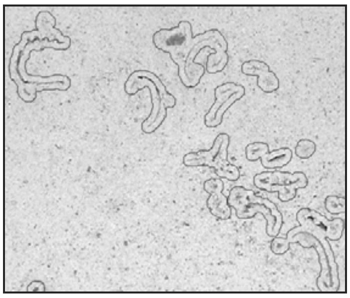


Fig. 8 Identification of linear and nonlinear defects in the test image shown in Fig. 1 (a)

Some inclusions, like the sections of fossils present in one of the test images (Fig. 1 (b)), can be considered a defect and exclude the area or the opposite: the presence of fossils can determine the usage of that area of the stone plate for a specific demand. The algorithm identifies these areas as well as other defects (Fig. 9).

Fig. 9 Test image chosen as example of linear, spot and structured defect (Fig. 1 (b)), with all the defective areas identified

The three test images were chosen in order to demonstrate the capacity of the algorithm to detect the variety of defects that are usually seen at the facilities that receive stone from 14 different quarries for sawing.

III. Conclusions

The procedure previously described allows the automatic detection of defective areas in limestone plates, producing contour lines around the critical areas.

Considering that the final goal is to mimic the actions of a human operator, who would mark the defects with a piece of chalk leaving a border of a few centimeters, which is needed to ensure clean cuts by the next machine in the processing chain, the final mask is dilated and rounded before extracting the contour lines of the defects (Figs. 6, 8 and 9), providing the necessary margin.

The location of the defective areas is a very important task, crucial to the next operation in the chain of production that is the optimization of the cutting process. The correct identification and location of the defective areas allows for maximizing the number of individual mosaics of a particular size that can be obtained from a single stone plate.

The methodology was tested in limestone plates where defects had to be localized in non-uniform backgrounds as the work images document, so we expect it will work also in other ornamental stones presenting more uniform backgrounds, which are not available at this facility. Moreover, this approach allows the construction of a database of classified stones to search the storage park in the posterior processing phases, opening the possibility of pairing stone plates with similar features to fulfill large orders of a particular types of mosaics while working at a computer, dispensing with the need for physical manipulation of the heavy stone plates at the facilities, which are the main source of work-related injuries.

All these combined are relevant aspects that lead to increased quality of production and gains in the productivity of the manufacturing process, contributing to increase workplace safety and diminishing accidents.

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