An Automatic Classification of Materials Degradation

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Abstract

A novel model to achieve a mathematical formalism for an automatic classification of materials degradation kinds is proposed. In the image analysis phase, wavelet transform local maxima are computed in order to detect the degradation shapes edges. In the second phase, at first, the shapes are encoded by the chain code and, then, a grammar is found to describe degradation kinds. Finally, for simulating further degradation processes, we are able to synthesize shapes boundaries examples, by means of both the found grammar and some additional rules.

1 Introduction

In many countries and especially in Italy, Cultural Heritage represents a huge, artistic and cultural, inheritance. Therefore, in order to preserve such a treasure, some methods and techniques have been, and must be, developed [1, 2].

This paper [1] shows an approach in order to realize a formalized representation for an automatic classification of degradation shapes, starting from images. This model can be an useful tool to support the "naked eye" analysis traditionally carried out by Cultural Heritage experts. In this context, an automatic classification is, more properly, an objective characterization of the procedure carried out by the expert (cfr. 2). Starting from such formalization we are able to simulate further degradation, overlapping both shapes extracted from other images and new shapes to partially degraded images. Moreover, we could think, by means of such an approach to achieve the recognition and the classification of different degradation kinds, using their features.

[1]This paper has been partially supported by CNR Finalized Project: "Cultural Heritage".

If we start from an image showing a material subject to a given kind of degradation, the first operation is the shape extraction. To do that, the Wavelet Transform (WT) can be evaluated a powerful tool to extract interesting features, since it is able to examine the information included in the image at several scale levels [3, 4, 5]. Now, because of the kind of considered degradation, we have to deal only with shape boundaries. Then, the boundary of the shapes relative to degradation zones is encoded by means of a well-known technique: the chain code [8, 9]. Starting from the obtained strings, we can generate a grammar [10, 11, 12, 13]. We stress here the fact that, by means of the help of Cultural Heritage experts, only a subset of all extracted shapes is singled out and, then, "chain coded". Such a basis will contain the most representative shapes. Moreover, the grammar can be considered both an objective representation of knowledge of the Cultural Heritage experts and a "box of information" about real images.

To synthesize the shapes, we don't generate only the shapes contained in the starting basis, but some new ones obtained from them.

After all, in this paper we want to generalize the considered methods, in order to both achieve an objective characterization of degradation notions and define functions of an automatic simulator that could assist in material degradation studies.

The paper is organized as follows. Section 2 contains more details with regard to the problem we are considering. The model description is made in section 3 and some experimental results are included in section 4. Finally, section 5 draws the concluding remarks.

2 The Objective Characterization Problem

In order to define in detail the problem, in this section we outline the aims and the constraints leading us to make some choices.

Starting from images showing historical building stones, the achievement of an automatic tool able to simulate degradation shapes represents the aim of our research. This operation is based on the analysis of peculiarities relative to different kinds of materials degradation. For the sake of truth, yet references can be found, describing materials degradation kinds, on the basis of their features, developed by cultural heritage experts (Normal and Rilem) [2]. Nevertheless, the available representation of the experts knowledge is very subjective, even if it is described by a very precise terminology. So, the main aim of this paper is the first attempt to generate an automatic characterization, i.e. a more objective representation of this knowledge containing the experience of cultural heritage experts. In this way, an objective classification can be achieved. In this paper we only consider some kinds of materials degradation which are characterized by material loss or breakdown in continuity.

Usually, since the internal texture of degradation zones can coarsely be approximated as uniform background, we can only deal with their boundary.

Therefore, in order to choose an efficacious boundary technique, we have to take into account these three constraints:

1. high precision in boundary representation. In fact, the representation technique must be able to recover the shapes very accurately. This constraint goes up from the fact that the analyzed shapes represent degradation zones. These ones have a lot of information that is contained in the boundary sharp corners;

2. possibility of extraction of generated codex sub-parts. In other words, the codex generated by a boundary encoding technique corresponds to the whole considered shape. Since we want to produce new degradation shapes, a boundary encoding technique is necessary which allows to extract some subparts. In this way, original shape sub-parts will constitute new generated shapes.

3. adaptability to a grammar. This constraint is obvious, if we want use a syntactic approach.

[2]Normal is for "Normativa Materiali Lapidei" - Commissione CNR - ICR; Rilem is for "The International Union of Testing and Research Laboratories for Materials and Structures"

Because of the fact that these constraints are strongly correlated, we have to keep all in mind, in order to make our choices. The result of these consideration leads to consider the *chain code* as the optimal choice in combination with the syntactic approach.

Using this approach, in fact, we can generate new shapes, with an high precision. On the contrary, in order to generate new shapes, we would obtain worse results using complicate primitives — having a given shape. Moreover, the chain code allows to get no loss compression. More complicate primitives would allow the compression but we would have a lower precision degree, in opposition to the aims of this paper.

With regard to the syntactic approach, in order to reduce the production rules number, we made the choice of the context-free instead of a regular grammar. Since we deal with a limited size language, we have two ways to make the grammar. The first one is the manual inference that we used [6]. If we want achieve also the compression, the second possibility is the Huffman or the cascade of Lempel-Ziv techniques. In both cases, we make a grammar able to generate only the basis shapes.

3 Model Description

On the ground of the previous section considerations, we can describe the proposed model, as shown in figure 1.

"Shapes Extraction" is the first block. It contains operations which take into account the fact that there are many irregular features in images showing materials degradation. Hence, before detecting the edges by means WT local maxima [7], some operations of interesting features enhancement have to be made — such as median filtering, contrast stretching[8]. With the help of cultural heritage experts, we could individuate, among extracted shapes, a subset of them, containing the most representative ones. In such a way, we determine the basis set.

Starting from our basis shapes, we obtain their strings, i.e. the code words by means of the chain code. Hence, we find a context-free grammar generating this language [6]. So, we "trapped" the information contained in the representative shapes only.

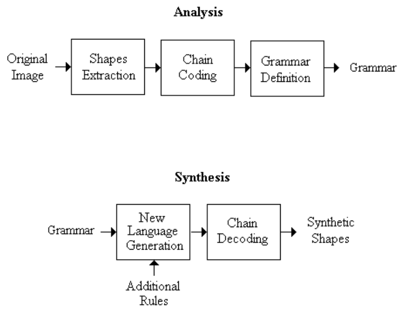

Figure 1: Proposed model blocks scheme: analysis and synthesis.

In the synthesis phase, starting from both generated grammar and, in case, an additional rules set, we generate the language that contains the old and new interesting strings — i.e. shapes.

In addition to the "closed shape" constraint, we have to impose further constraints — being context-dependent and hence suggested by experts— in order to produce manipulations of the starting strings. In other words, the additional rules have got to take into account experts knowledge and/or results of mathematical models studying, for instance, the fluid-dynamic behavior of the material. The additional rules are local and they represent little changes of the basis strings. If we now decode the obtained language, we get a shapes set including the basis.

Let's see now some details relative to the language we mentioned in the model.

In 4-connectivity, if we associate the first lower-case symbol (i.e. n, s, e, w) to each one of four vectors, the language L generated by the grammar G will only contain these symbols. Obviously, the above L language will only contain the basis shapes strings extracted from the original image.

The generation of $L^\star$ language ($\supseteq L$), containing both basis and new shapes, is made as follows. If s is a given string and p_s the starting point, the valid strings must satisfy the constraint:

$$\tilde{s} = \sum_{i=1}^{|\tilde{s}|+1} \mathbf{v}_{p_i,p_{i+1}} = 0 \qquad p_1 \equiv p_s \equiv p_{|\tilde{s}|+1}, \tag{1}$$

where $\mathbf{v}_{p_i,p_{i+1}}$ is the vector having p_i as application point, from p_i to p_{i+1} versus. This constraint is equivalent to the request that generated strings correspond to closed zones in the plane. Moreover, this constraint is the only one to be imposed to new strings — the strings contained in the basis already satisfy it.

The choice that the grammar generates only the basis shapes, allows to not complicate the grammar generation, since the basis shapes number might usually be not very large.

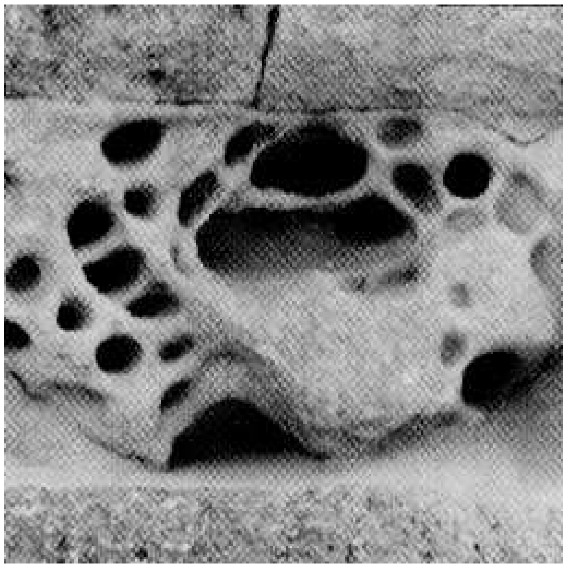

Figure 2: 256*256*8 bit original image: pudding stone with degradation as cavities.

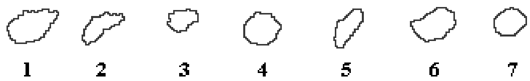

Figure 3: Examples of extracted shapes taken as a whole.

4 Experimental Results

The proposed model has been tested on several images. Nonetheless, for the sake of brevity, we give here only two representative examples.

Figure 2 includes the first original image showing a pudding stone containing cavity-shaped degradation.

The shapes have been detected by means the wavelet transform local maxima technique. The

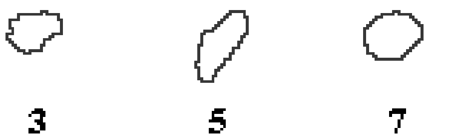

Figure 4: The basis set: representative cavities.

Cavity Grammar

$S \equiv$ Start symbol;
$V_t \equiv \{s, e, w, n\};$
$V_m \equiv \{0, 1, 2, 3, 4, 5, 6, 7,$
$\quad A, B, C, D, E, F, T, U, Z, V, Y, W, X\};$
$R \equiv \{$

$$0 \rightarrow se, \quad 1 \rightarrow sw, \quad 2 \rightarrow nw,$$
$$3 \rightarrow ne, \quad 4 \rightarrow es, \quad 5 \rightarrow en,,$$
$$6 \rightarrow ws, \quad 7 \rightarrow wn$$
$$S \rightarrow sZ, \quad A \rightarrow w6^2, \quad B \rightarrow 7w^2,$$
$$C \rightarrow s^2 0, \quad D \rightarrow w^2 s^2, \quad E \rightarrow en^2,$$
$$F \rightarrow eE$$
$$Z \rightarrow 6^6 w A s^3 6 s^5 6 s U,$$
$$U \rightarrow 4 s^3 4 e^2 F E 5^3 n T,$$
$$T \rightarrow (FE)^2 5_2 n^5 w n^2 w^5,$$
$$Z \rightarrow w^6 D w D 0 s^2 D 4^4 Y$$
$$Y \rightarrow e^2 s^2 e^2 3 e^2 E^2 e 5^2 V$$
$$V \rightarrow e^3 n^4 2 n^2 w^3 B$$
$$Z \rightarrow w A^2 6^3 W$$
$$W \rightarrow s^2 C^2 4^2 5^8 n^4 X$$
$$X \rightarrow 7^4 B^2$$

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Figure 5: Grammar relative to cavity-shaped degradation of a pudding stone.

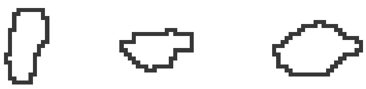

Figure 6: Examples of new cavities.

Figure 7: 512*512*8 bit original image: pudding stone with degradation as fissure.

Figure 8: The basis set: representative fissures.

Fissure Grammar

$S \equiv$ Start symbol;
$V_t \equiv \{s, e, w, n\};$
$V_m \equiv \{0, 1, 2, 3, 4, 5, 6, 7,$
$\quad A, B, C, D, E, F, G, T, U, Z, V, Y, W, X\};$
$R \equiv \{$

$$0 \rightarrow se, \quad 1 \rightarrow sw, \quad 2 \rightarrow nw,$$
$$3 \rightarrow ne, \quad 4 \rightarrow es, \quad 5 \rightarrow en,$$
$$6 \rightarrow ws, \quad 7 \rightarrow wn,$$
$$S \rightarrow eZ, \quad A \rightarrow se^2, \quad B \rightarrow 2nw^2,$$
$$C \rightarrow sw^3, \quad D \rightarrow e^2 s, \quad E \rightarrow wn^2,$$
$$F \rightarrow w^3 n \quad G \rightarrow n^2 7,$$
$$Z \rightarrow e^2 A^2 n e^2 3 0 s^2 e^3 (0A)^3 D A T,$$
$$U \rightarrow w^2 n w^2 C 2^2 w^2 B^3 E w^2 C n w^3 2 n,$$
$$T \rightarrow n e^3 A e n e^3 3 n e^2 n e^3 C 1^3 w^2 C U,$$
$$Z \rightarrow s 4 e^3 s D^3 e^2 n e^3 s e^4 s D e^3 n D e^2 n 4 D V$$
$$Y \rightarrow w n^2 w^4 1 n F 7 F^2 s (w^2 n)^2 F^2 7^2$$
$$V \rightarrow 4^2 s e^3 s^2 e^2 0 s^2 D 4^2 s E 7 E^2 w^2 n^2 F 7 Y$$
$$Z \rightarrow s^3 4^2 0 s^3 4 0 4^2 0 s^4 4 6 0 s^6 e^2 s^5 W$$
$$W \rightarrow 4 e^4 s^2 4^2 0^2 7 w^4 n^3 7 w^2 2^2 7 n^2 7 2 n^2 X$$
$$X \rightarrow 7^2 e n^2 7 e n^4 7^2 e n^2 7^2 w^2 n^5 7 2^2 n^2 7$$

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Figure 9: Grammar relative to fissure-shaped degradation of a pudding stone.

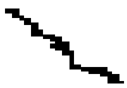

Figure 10: An example of new fissure.

figure 3 shows the extracted shapes set, obtained from the first block of the scheme. Obviously, we could extract an higher number of cavities from the original image than that shown in figure 3. Nonetheless, in order to not complicate the example exposition, we can consider a subset of them, taken as a whole, without generality loss. So, we have only seven shapes. With the experts help, we can determine, among them, a shapes subset representing our basis, containing, for instance, the third, the fifth and the seventh shape [3], as shown in figure 4. The help of Cultural Heritage experts is required if we want that the number of the shapes in the basis is small and including only the interesting shapes.

If we encode the shapes contained in the basis, we obtain a strings set — in this case three. Starting from the latter, the grammar, shown in figure 5, [4] is generated. In the "cavity grammar", we outline that there are two production rules kinds. In the first one, we have the rules that have a number as first non-terminal symbol. Such rules, representing all the combinations of utilized terminal symbols, are common to all grammars of this model. In the second kind, the rules, having an uppercase letter as the first non-terminal symbol, are peculiar to the considered grammar.

In figure 6, some examples of new generated shapes are shown, starting from the three shapes contained in the basis. To do this, we can put an additional rules set, which represent a sort of transformation of basis shapes. Transformation is for local operations applied to boundary subparts. Usually, every additional constraint can be coded in geometric features.

Figure 7 shows the second original image which includes another example of degradation of a pudding stone: a fissure. The basis relative to this degradation kind is contained in figure 8, in order to generate the "fissure grammar" (see figure 9). Finally, in figure 10 an example of new fissure shape has been generated.

We have to say that, in order to check if the generated shapes, as in figures 6 and 10, are "good", we can use a subjective and an objective test. The first one is the opinion of the Cultural Heritage expert. The second one can be represented by measures, such as shape perimeter etc. We can apply these measures to the basis, obtaining, for instance, a gaussian p.d.f., and then to a generated shape. If the latter falls in the basis distribution, we can say that it is a "good shape". Moreover, such an approach can be considered an useful tool, to recognize shapes of materials degradation.

[3] In this case, the choice of the shapes has been made without specific consideration, but it represents a simple example only.

[4] The $symbol^n$ notation is equivalent to the string containing n times the *symbol* symbol.

5 Concluding Remarks

In this paper we have shown a model able to characterize and generate further degradation of materials, starting from significant images. In order to do that, firstly the shapes have been extracted by means of WT and their boundary is encoded by the chain code. So a syntactic approach is used. Such a model can be considered interesting, since it is able to generate both the real images degradation shapes and new shapes. Moreover, such an approach may be used in the degradation recognition, whenever two or more degradation kinds are considered.

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