Synthesis and Transfer of Time-Variant Material Appearance on Images

Djalma Bandeira and Marcelo Walter
Centro de Informática - UFPE, Brazil
{dbs, marcelow}@cin.ufpe.br

Figure 1. Weathering process effect of rusty transferred and synthesized from a sample to the statue on the image.

***Abstract*—The modeling of weathering effects in still images is a powerful editing tool for many graphics applications. Although most of these effects can be generated by manually creating textures through graphics editing applications, performing such artist work is time consuming. More sophisticated and automatic solutions to simulate a wide variety of weathering effects become essential. We present a method to generate and transfer weathering effects on images based on chroma distribution and luminance manipulation. Our solution has three main contributions over prior work. First, we propose an alternative solution to appearance manifolds, called appearance maps, to help synthesize variations in appearance in objects due to weathering effects. Although powerful, appearance manifolds are costly to build. The use of appearance maps allows real-time editing of images. Second, we extend the technique by using texture mapping ideas to allow the inclusion of weathering effects on images without them. Finally, we provide a mechanism to properly handle highlights, extending the range of possible images for manipulation. The results illustrate the flexibility of our solution and we also present results comparing real and virtual decay processes. Applications of this technique include virtual restorations of objects and images, as well simulation studies on future appearance of objects under environmental influence.**

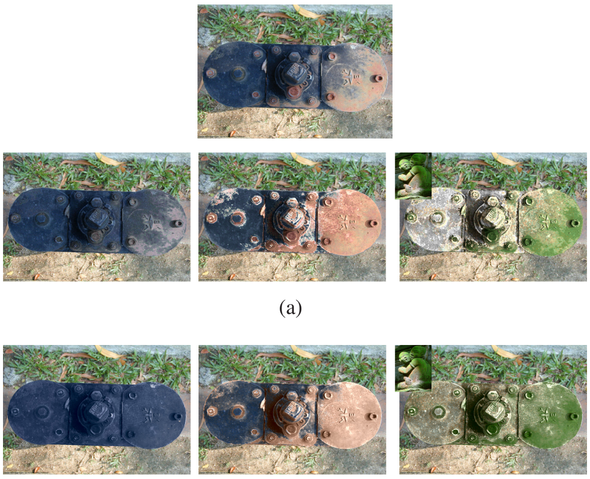
***Keywords*-image processing; image synthesis; image restoration; texturing techniques;**

I. Introduction

The manipulation of still images is a powerful resource in many graphics applications. However, most of the available methods are based on manual artistic composition of images and the textures on them. Besides, they usually consider only static state of materials without taking into account the variations in appearance due to natural aging. Just recently, the research community has started to address the issues related to modeling variation in material appearance due to environmental factors. We use both terms, weathering and time-varying, to express the same concept of a material appearance changing over time.

The modeling of material appearance over time allows the creation of a branch of effects from the same basic state of the material. While some works apply techniques considering a whole 3D virtual environment, others address aging and weathering on still images through the analysis of colour and luminance parameters from the image. Two examples of these are [1] and [2] that inspired our work. Our contributions in this paper are as follows. Instead of building an appearance manifold, we build an appearance map, a much simpler structure used to implement the weathering and deweathering effects. Fig. 2 shows that we can obtain good results using this approach in comparison with the related work [2]. Second, we use texture mapping to allow the inclusion of weathering effects on images without them. This is also combined with shape-from-shading techniques to estimate normal vectors on images and enhance the mapping effect. Third, we propose a solution to handle images with highlights, extending the range of possible images for manipulation.

Using the method we propose here allows the manipulation of images that present a content of developed state of weathering. Based on this information, we model an evolution aging system and obtain new states of the image in time by weathering or deweathering its original state. In this way it is possible to simulate the weathering process of images covering a good variety of effects, generating pleasant results in most cases. This can not only be applied on texture



(a)

(b)

Figure 2. Results by Xue et. al [2] in (a) and our method in (b). Our results were computed in a few seconds.

material samples, but also on images with complex scene and geometry that are hard to estimate. A strong advantage of our technique is the ease to generate and preview the effects in real-time. This allows better adjustments and experimentation of parameters to achieve the results that best fit the user needs, in less time. Another advantage is the combination and transfer of effects in a flexible way to generate varying image compositions more visually accurate. These operations usually require a minimum user input which is restricted to basic parameter adjustments. Fig. 1 shows a material transfer involving a rusty effect.

II. Related Work

The modeling of weathering phenomena in graphics is not new. The first approaches appeared in mid 90's, although just recently more formal studies on this subject have been published, such as the book by Dorsey and colleagues [3] which introduces a weathering taxonomy divided into chemical, mechanical and biological categories. Another example is the survey presented in [4], where a classification of aging phenomena is introduced.

Many of the material appearance modeling methods address the simulation of specific effects, and therefore they include a detailed study of the application domain. This ensures more accurate results and better controllable behavior of the related effect. Already in 1996 Dorsey and Hanrahan [5] presented a solution to simulate patina formation followed by an in-depth study of the effect. Another interesting work is [6], that introduces a model to simulate the weathering process of stones. Methods considering rust and corrosion are presented in [7] and [8], respectively. Techniques that reproduce effects related to wet and drying are proposed in [9] and [10]. Some approaches involving the simulation of cracks are presented in [11], [12], [13], [14], [15]. We must also mention other works related to mechanical effects such as dust [16], [17], [18], scratches [19], and impacts [20]. Furthermore, a good case of biological effect simulation involving lichen growth is introduced in [21]. Research such as presented in [22] and [23], provide the generation and combination of a mixed set of effects.

Two very recent methods that deserve special attention are presented in [1] and [2]. Both focused on modeling weathering effects in 3D objects and images advancing the key insight idea that a given image contains all needed information to compute weathering and deweathering states of an object, for a variety of effects. Our work follows some basic features presented by them, such as user interaction and decomposition of image information into shading and weathering. These two papers use the appearance manifold approach in order to model the weathering distribution, whereas we use an alternative, straightforward yet effective method, called the appearance map, to handle this information and generate new weathering states.

III. Method

The scheme presented in Fig. 3 provides an overview of our system. The input information is an image where there is a foreground object which will undergo the weathering changes. On this image, the user selects two pixels located in visually distinct regions of weathering. This is the same initial step as introduced in [1]. From these two points we will build our appearance map, which is a simple color map explained below. This map is instrumental to handle the initialization and synthesis of weathering information. After that, the user can choose between de/weathering composition or material transfer operations.

As an alternative to this generation procedure, the user can directly import, into images that have no weathering information, effects previously processed, or when different effects and patterns are desired. Therefore, the user has two choices of weathering synthesis: weathering degree estimation and weathering distribution mapping.

A. Building the Appearance Map

The first step is to segment the image into regions of interest through pre-defined masks that can be manually created using a graphics editing tool. On the target object selected for edition, the user then selects two initial control points by choosing pixels located in what would be considered the least and most weathered regions respectively. They will control the weathering estimation process later on the appearance map. The appearance map (Fig. 3(a)) is a plot, in the ab-plane of the Lab color space, of a subset of colors present on the image. During weathering and deweathering steps, the appearance map will provide the information for the next state of a pixel's color. Walking on this map in order to determine the next pixel's color is much simpler than walking on the appearance manifold [1] [2], and therefore

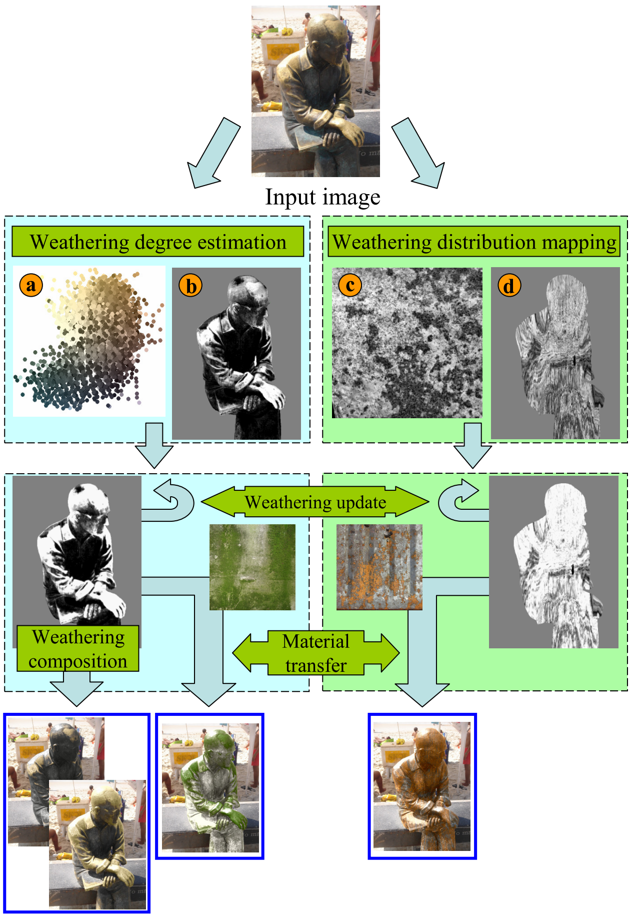


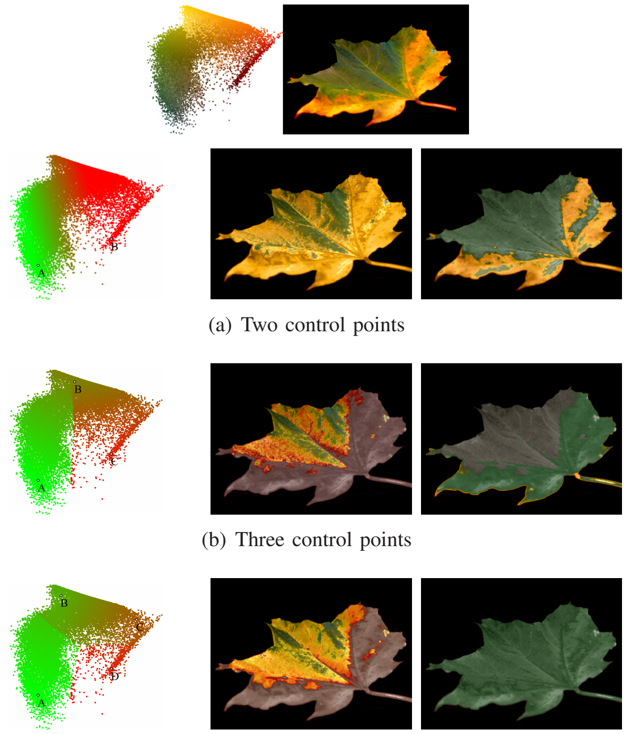
Figure 3. General scheme showing the basic steps of our system.

this possibility increases the overall performance, allowing real-time results when processing new weathering states. Besides, it is a more intuitive representation of the color distribution and an alternative way for point selection.

Alternatively, candidates for starting and ending points can be automatically assigned without user intervention, based on the point distribution and density on the appearance map. Intuitively, the two control points define the range of colors considered for manipulation. If a given set of control points do not cover a wide range of the appearance map or are badly distributed, the user can refine the process by selecting new candidates directly on the image or picking these in the appearance map as well.

Since the number of pixels is relatively high, we do not map all pixel's colors to the appearance map. We use a downsampling factor that controls the fraction of pixels to be covered on the image. Tests show that even using high factors we can increase the overall process performance with a minor impact on visual quality.

In order to deal with non-trivial cases where three or more color transitions of the weathering effect are present, the user can select more than two points for a better color



(a) Two control points

(b) Three control points

(c) Four control points

Figure 4. Effect of adding more control points in the appearance map. Appearance map on the top left.

variation control. Fig. 4 illustrates this possibility, where we show an image of a maple leaf with three sets of appearance maps, weathered and deweathered with different numbers of control points: two, three, and four. Notice how with four control points, both degradation and restoration processes are visually more convincing. The plots on the left illustrate the weathering distribution, where the least and most weathered states are colored from green to red respectively. They provide a visual clue on how well our choice of points covers the whole set of colors. The user will judge the need for more control points for better weathering estimation based on the colour variation of the input image.

B. Luminance and Weathering Decomposition

With the control points properly selected, we need to establish a correspondence for every point in the appearance map to a certain weathering state. We approximate the weathering state to its position in the appearance map by considering a line segment that starts at the minimum weathering point position to the maximum weathering point position on the map. We use the Lab color space [24] to properly treat image colours and luminance as separated image attributes. Therefore, while the chroma channels (ab) are used to define the weathering degree, the luminance channel (L) is used to estimate reflectance and illuminance properties. We assume that all color variation is only due to time-varying phenomena.

To define a weathering state for every point on the map, we take the closest point in the line segment to it, and associate the position of that point as the weathering degree. This parameter tells how weathered a certain point is within the weathering system relative to its closest distance on the line segment. This step is illustrated in Fig. 5. Although simple, this approximation provides good visual results.

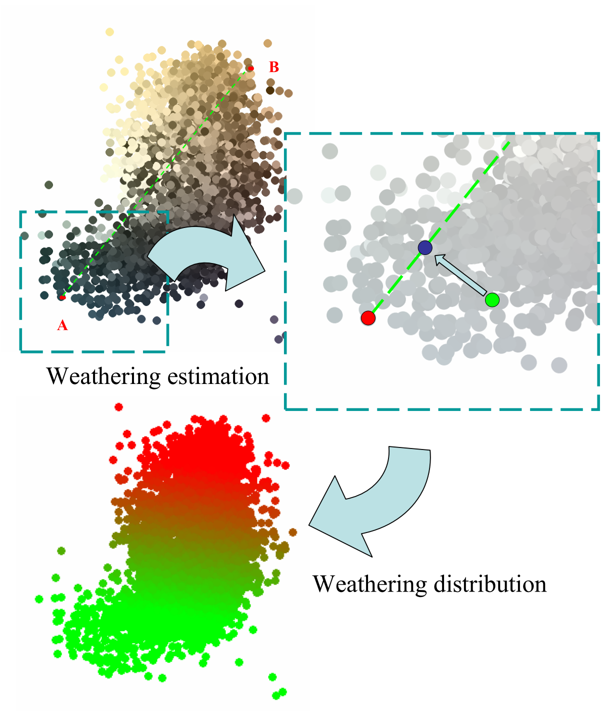


Figure 5. Consider the line segment $\overrightarrow{AB}$. The weathering degree of a point (green) in the appearance map corresponds to the position of the closest point (blue) in the segment.

The weathering degree will be referred to as D and its distribution on the image visually represented as a weathering degree map, like Fig. 3(b) on the scheme previously introduced. Its value is within the $[0.0, 1.0]$ range, where 0 is the least and 1 the most weathered point. Points that fall outside the range limit are clamped to the end points of the segment. This usually have little to no impact on visual results, considering that the number of clamped points is negligible for a wide range covered on the appearance map. If working with more than two control points, the method is still the same, we just make the segment for each pair of points to assume a relative interval in the absolute range $[0.0, 1.0]$. The relative intervals are evenly assigned according to the number of pairs, but can also be adjusted by the user to affect the color variations on weathering process.

We use the method presented in [2] to decompose the luminance channel as the product of weathering and shading components as $L = W \times S$, since it is fast and generally leads to pleasant synthesis results. After weathering degree decomposition, every single point in the appearance map has its own weathering degree D and decomposed weathering and shading components defined. This will ensure that while the original shading remains unchanged for every update on image pixels, together with chroma transition, a new reflectance luminance from the weathering component will be assigned as well. This feature allows to modify the chroma and reflectance variations over different degrees of weathering and still preserve the original image shading.

Special care must be taken with highlight pixels. In the paper by [2] the results did not present any image with highlights. In our approach, as a last preprocessing operation, we generate a high luminance level distribution layer to better model and preserve specular highlights. We approximate the highlight level as $S_h = e^{L/h_s}/e^{h_s}$ for every pixel, with highlight sensibility h_s set to 10.0. This will be used in the final synthesis step to recover highlight levels that may have a wrong appearance assigned in high specular regions, particularly on cases where specular highlights are not affected by weathering. Fig. 6 illustrates how the highlight recovery makes the result look more natural.

(a) (b)

Figure 6. Example of deweathering process without (a) and with (b) highlight recovery.

C. Weathering State Update

Now that every pixel in the image has its weathering degree defined, in order to synthesize a new weathering state, we update this value and adjust all pixels accordingly. Here is where the propagation factor P is introduced, controlling how the weathering effect progresses and spreads over the image. We define the visual representation of the propagation factor for every pixel as a propagation map. The standard procedure for building the propagation map is to average the weathering degree of every pixel with its neighborhood, ensuring that the weathering effect will follow the same pattern presented on the initial image state.

After the propagation factor is defined, we have to properly update the weathering degree based on it. To obtain a new weathering degree D' for every pixel, we establish an incremental value for D based on the respective pixel propagation P, and the adjustable parameters speed factor K_s and weathering factor K_w. K_s is a relatively low value (0.025 as default) that controls how fast the weathering synthesis is processed, whereas K_w allows a local weathering composition that depends directly to the current D. For a more natural look, we can define K_w as a Gaussian function. If a global weathering is preferred, we set $K_w = 1.0$ to process the weathering at the same rate in the whole image. We update the weathering degree as:

$$D' = D + (P \times K_s \times K_w). \quad (1)$$

To avoid unexpected results for values beyond the limit, we restrict the weathering degree to a certain threshold (set to 0.98 in our tests). Following this last step, we identify good substitute candidates for all pixels based on a weathering degree approximation and a minimum luminance error. To search on the appearance map points for new candidates of a certain pixel, we first consider the minimum weathering degree distance $\Delta D = D_c - D$ between them, where D_c is the weathering degree of the candidate to be evaluated. One second condition for a good substitute candidate is related to the luminance variation. We only consider those points whose luminance vary no more than a certain threshold ω (20.0 as default) relative to the initial luminance of the original pixel on the image. This helps to attenuate artifacts caused by chroma noise, mostly on dark regions. If there are no candidates satisfying the luminance condition, the closest one in terms of weathering approximation is chosen.

All the pixels will now have their chroma values ab and the weathering component W replaced by the one stored on the chosen candidate point. A new luminance L' for every pixel will be computed with the updated weathering component W' using the same shading as $L' = W' \times S$.

The last step in the synthesis process is to recover possible specular highlight regions, as it was mentioned before. Considering the color c for every pixel, its highlight level S_h, and the specular color S_c, we obtain the final color C using the following equation:

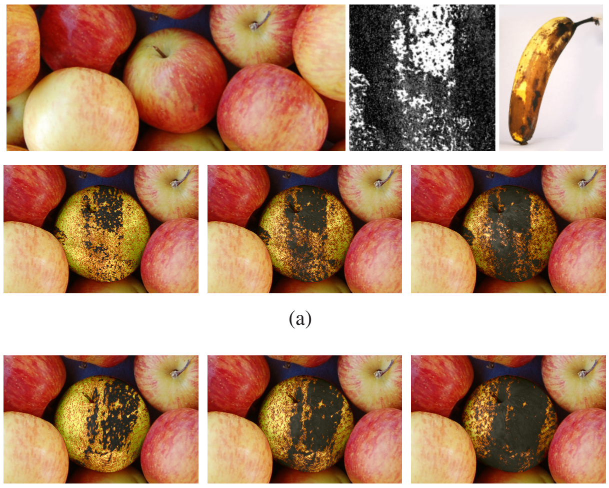
$$C = c \times (1.0 - S_h) + (S_h \times S_c). \quad (2)$$

For deweathering operations, we simply invert the order of the control points and redefine the weathering degree distribution. This will ensure a reverse weathering synthesis that progresses in most-to-least order.

D. *Transfer of weathering features*

To perform the material transfer we replace the chroma ab and weathering component W information from the current material to another similar material data previously processed and saved. The transfer still considers both weathering approximation and minimum luminance variations during per-pixel operations, oriented by the weathering degree from the input data associated with the state of the current material. It will keep the relation of weathering and chroma distribution between the related materials and yet preserve the original material shading information.

Another example of transfer refers to weathering distribution mapping on the image (see Fig. 3(c) mapped to Fig. 3(d) as an example). In this case, we can transfer the weathering information processed from other materials as a weathering degree map in order to obtain their weathering look and distribution. While a simple texture mapping operation can be applied to rescale and fit the weathering degree map onto the image selection being processed, the use of shape-from-shading techniques, such as presented in [25] and [26], can better fit the distribution with the geometry shape on images. This can be particularly useful in cases where the shape is smooth and provides an acceptable normal estimation from image luminance. An example of good use of weathering distribution mapping is shown in Fig. 7.



(a)

(b)

Figure 7. The flat appearance caused by a simple texturing mapping (a) can be improved by a normal-oriented mapping (b) and adjusted to the shape of the objects.

Although the shape-from-shading technique used does not generate precise shape approximations, it is still suitable for our method with minimum adjustments to obtain reasonable visual results. Fig. 8 shows how we can obtain varying weathering compositions just by using different weathering distribution maps and samples. The final step to recover the original image highlight is executed as before.

IV. Results

The results presented in this paper were all generated on an ordinary laptop with an Intel® Celeron™1.8GHz processor and 1GB memory. Considering worst-case images with resolution of $2200x1680$, one frame is processed within ten seconds with a downsampling factor of 16. Transfer of weathering effects in these cases takes up to five seconds.

Fig. 2 presents a comparison between our approach and the one introduced by [2]. Their method generates convin-

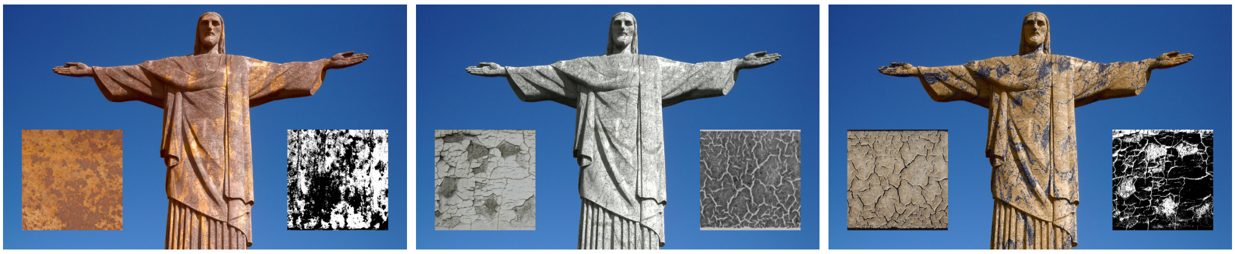


Figure 8. Combinations between weathering sample (left) and distribution (right).

cing results, but its time requirements turn interactive real-time manipulations and tests impractical. Ours, on the other hand, can not only generate visually similar images in just a few seconds but are also visually coherent when compared to the previous work. The weathering and deweathering operations using our approach show better preservation of the rusty features, a more consistent restoration to the object details, and that the luminance failures are less prominent when compared to the reference. Besides, our result of material transfer presents more color details and variations.

Fig. 9 shows a few frames of a deweathering process for a very damaged Thinker statue. Notice how we can obtain advanced restored stages without compromising the geometry details and highlight information on the image. This example illustrates a possible application for artists in restoration of antique art pieces.

Fig. 10 illustrates the use of weathering distributions to include variations of moss growth effect. Designers and artists alike could use this to understand how a building or a statue, will look in the future in an outdoor environment.

The last example is an attempt to check how well purely editing operations on images compare with a real process. In Fig. 11 we show a case study involving the decay process of a banana. The frames of the real process were taken 24h apart from each other. Ignoring the small shape variations and the fact that the overall colour changes on the reference is not well modeled, our method still approximates the weathering look and propagation on a real banana. An interesting topic for future work is to use additional information from case references to make the weathering simulation process more physically accurate.

V. Conclusions

We presented an approach which allows to easily perform weathering synthesis and transfer of materials on images at interactive rates in contrast to other methods previously proposed in the literature [1], [2]. Our method replaces the appearance manifold for an appearance map, with considerable gains in performance. In terms of user experimentation and interactive tests, images can be processed by our method in a matter of seconds against minutes on the method by [2], let alone the pre-processing stage for the appearance manifold construction. We can generate new weathered states related to aging characteristics on the content of the source image and still preserve geometry details. We can also import weathering information from other materials to associate and transfer the effects with the original weathering of the images, or apply new effects on weathering free images.

Our solution does not address weathering effects with rough geometry variations, a problem already mentioned in [2]. Another problem is related to weathering distribution mapping involving severe luminance and shape variations. In these cases, the shape-from-shading causes an inaccurate normal recovery, leading to mapping failures.

As future work, we may try to decompose the shading into a partially editable component to model weathering related geometry variations, such as wrinkles and cracks. Another important subject to consider is the transfer of materials with specular highlight information, ensuring a more accurate model. We can also take advantage of propagation maps to control the weathering process locally instead of globally, by just adjusting the propagation factor of specific regions. This can be used to orient the weathering to a certain direction, or to rearrange it dynamically if needed. Another use of these maps is to transfer propagation patterns from other materials, or even elaborate new configurations based on noise [27] or perturbation [28] functions, for example. We may also consider the use of shape-from-shading methods to modify the local processing on propagation maps based on accessibility information according to the shape approximation to apply effects like blemish and dust accumulation. These improvements will allow a more precise appearance modeling for intrinsic characteristics of certain materials.

Our work can help as a motivation for additional computer graphics tools to easily compose textures with variable weathering effects. We can also extend the applications to a 3D domain by combining our approach with techniques such as bump mapping [28] and ambient occlusion [29].

VI. Acknowledgment

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Figure 9. The restoration process of the Thinker statue.

Figure 10. Various moss growth effects on an old house.

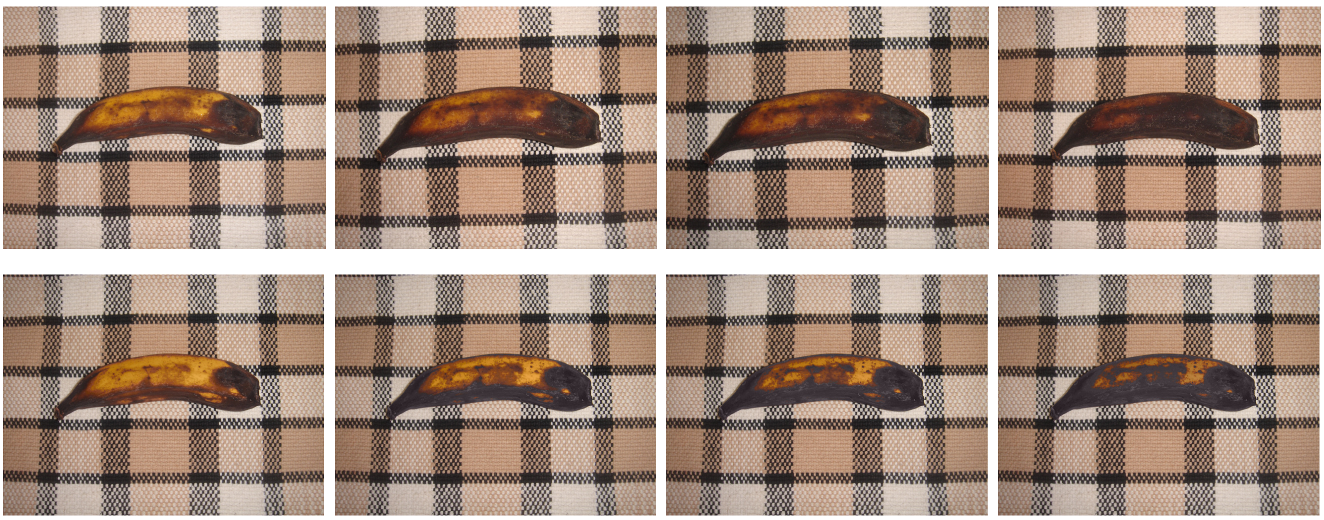

Figure 11. Comparison of a decay process on a banana. Real images (top row) and synthesized images (bottom row).