

REAL-TIME WETTING OF POROUS MEDIA

Kevin HNAT, Damien PORQUET, Stéphane MERILLOU and Djamchid GHAZANFARPOUR
Laboratoire XLIM UMR 7162, Université de Limoges, hnata@msi.unilim.fr

September 14, 2006

Abstract. Studying light reflection properties is a crucial factor in achieving a high degree of realism in image synthesis. Considered as a challenge in itself, it becomes even more complicated when dealing with specific changes in appearance due to external factors. Among these changes, one of the most common is wetting: surfaces appear darker and more specular as their wetting level increase. Such a phenomenon is of great visual importance in outdoor scenes under rain falls for example. This change in appearance is mainly due to the porous nature of surfaces. In this paper, we propose to handle a porous surface BRDF post-process model in real-time and to extend it to account for wetting, with simple and intuitive parameters.

Key words: Shading, Porosity, Weathering, Wetting, Real-time rendering

1. Introduction

To further increase realism in rendering, light/matter interactions must be improved, in particular by accounting for changes in appearance due to external factors. A fundamental component driving reflection properties is surface micro-geometry, which can be visible or invisible. Visible micro-geometric object features can be handled by geometrical techniques [4] or fake-geometrical techniques [2]. Nevertheless, real surfaces exhibit many invisible micro-geometric features having visible effects. Among these features, roughness is taken into account by the great majority of Bi-directional Reflectance Distribution Functions (BRDF). Porosity is another microgeometric feature, often omitted in realistic rendering. However, it can modify significantly the optical properties of surfaces [3]. The proportion of pores onto surfaces can be very important (up to 40% in fired-clay bricks for example). Moreover, porosity is directly linked to numerous weathering processes. It is at the origin of destructive corrosion allowing chemical reactions to continue underneath the surface. Efflorescence is produced by wetting/ drying cycles inside materials due to their porosity. It plays a key role in numerous other weathering processes such as painted or varnished surface tarnishing. Porosity can also explain changes in appearance of wet surfaces, becoming darker and more specular. The simulation of porous materials and their associated flow processes can be very important in many fields, due to the very large amount of different natural or manufactured porous materials. This paper deals with a real-time simulation of porous surfaces (based on a model presented in [9]), as well as an appropriate simple extension permitting to take

Original Porous Model		
Name	Definition	common value
k_s	BRDF specular coefficient	$k_s + k_d < 1$
k_d	BRDF diffuse coefficient	$k_s + k_d < 1$
s_p	average geometry of pores (section 3.1)	$0 < s_p < 1$
m	Root Mean Square roughness	0 (not rough) $< m < 1$ (very rough)
α_{poro}	classical porosity definition (section 3.1)	0 (not porous) $< \alpha_{poro} < 0.5$ (classical) < 1
Wet surface model		
Name	Definition	common value
t_{fill}	average pores filling time	$0 < t_{fill} < 1$

Tab. 1. Summary of parameters used in the paper

into account a natural phenomenon, directly linked with porosity: wetting of porous materials. The main contributions of this paper can be summarized in the following way:

- We show how to implement real-time rendering of porous surfaces.
- We introduce a simple rendering model of wet surfaces, controlled by intuitive parameters, as shown in table 1. This is an important point as numerous studies are focussed on flow simulations but often lack realistic real-time rendering of wet surfaces.
- We show how to implement real-time rendering of wet porous surfaces.
- We show how to use the model in animation.

We first present related works in section 2. Section 3.1 deals with the model itself. Then, the proposed extension is detailed in its own section (3.2). We also present the obtained results in section 5. We finally conclude and present our future work.

2. Related work

Weathering phenomena in computer graphics are of great importance because of their major visual influence. Due to the large amount of different physical processes and their complexity, numerous studies have focused on specific weathering phenomena. These techniques can be empirical or physically-based and can affect the entire rendering pipeline (geometry, reflection properties, and colors). We only focus on wet surfaces in this section. In [10], Nakamae et al. uses a two-layer reflection model to simulate the presence of water puddles on a road. Darkening is empirically obtained by changing surface lighting components. In [6], Jensen et al. introduced the change in material behavior because of wetting, making materials darker, brighter, more specular or translucent. The model is based on a two layer surface reflection model. In [7], Lu et al. simulate surfaces

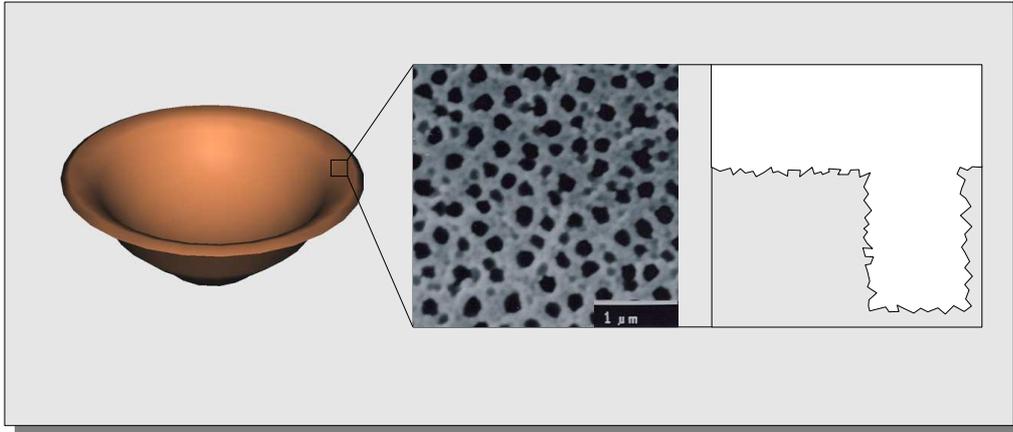


Fig. 1. A pixel may be covered by a large number of pores. Global behavior is modeled as a single pore behavior, inserted into local illumination surface model.

drying using parameters issued from captures made on real objects. Real-time wetting of surfaces, to our knowledge, have never been specifically studied. Liu et al. in [8] describe an on-surface flow system permitting to take into account numerous phenomena such as wetting. To render wet surfaces, a linear interpolation of color between two textures is made (a fully dry and a fully wet texture). In this paper, we provide a real-time model to take into account the wetting phenomena with simple and intuitive parameters, based on physical observations.

3. Overview of the model

3.1. The BRDF Post-Process

The BRDF post-process [9] introduces a perturbed cylindrical pore in the classical surface description used in local lighting computations [5]. Consequently, for each pixel, this pore behavior represents the average behavior of the pores projected onto the pixel's surface as shown in figure 1. Pores distribution is supposed to be uniform over the surface. Their behavior is considered individually (light absorption and emission in the pore) and follows some phenomenological principles:

- Incident light contribution to specular reflectance is replaced by a contribution to diffuse reflection. This substitution is modulated by a masking and shadowing term (see below). Indeed, a pore can be shadowed by hills of surface. This is due to the

perturbed nature of real pore shapes.

- Contribution of incident lighting to diffuse reflection is modulated by total energy loss, due to light penetrating into the material through interconnected pores.

These phenomenological rules can be applied to any BRDF that can be separated into a diffuse and a specular component. The model consists in introducing new specular and diffuse coefficients called k_{s-poro} and k_{d-poro} permitting to take into account for porosity. For a given separable BRDF $f_r = k_s F_s + k_d F_d$ (where F_d is the diffuse term and F_s is the specular term of the BRDF) the new model can be written as:

$$f_r = k_{s-poro} F_s + k_{d-poro} F_d$$

with:

$$\begin{aligned} k_{s-poro} &= k_s(1 - \alpha_{poro} G_p) \\ k_{d-poro} &= kd(1 - \alpha_{poro} G_p A_p) + k_s \alpha_{poro} G_p (1 - A_p) \end{aligned}$$

- α_{poro} is the ratio of surface covered with pores (common porosity definition)
- s_p is the ratio between the mean depth of the pores and their average diameter.
- G_p is the shadowing and masking term

$$G_p = \frac{(N.S)}{(N.S) - k.(N.S) + k} \frac{(N.V)}{(N.V) - k.(N.V) + k} \quad (1)$$

with $k = \frac{2m^2}{\pi}$, m the surface RMS roughness, N is the surface normal, S is the incoming light direction and V is the viewer direction.

- A_p represents the total light loss in the pore. With n_b (number of bounces of a light ray penetrating into a pore) and k_a (the total ratio of absorbed light, $k_a = 1 - k_s - k_d$), A_p may be written as:

$$\begin{aligned} A_p &= k_a \cdot \frac{1 - (1 - k_a)^{n_b}}{1 - (1 - k_a)} \\ n_b &= s_p \cdot [3.7 - 2 \cdot (\frac{\theta_i + \theta_r}{2} - \frac{2\pi}{s_p + 6})] \end{aligned}$$

More details on the porosity model can be found in [9]

3.2. Wet porous surface model

Pores are filled with water when water falls onto a porous surface. Our method is simply based on this observation. We do not consider the thin water layer that can be present on top of the material (see section 6).

Figure 2 exhibits local surface illumination used. Non porous part of the surface does not change. The pore is progressively filled with water and the behavior of water surface

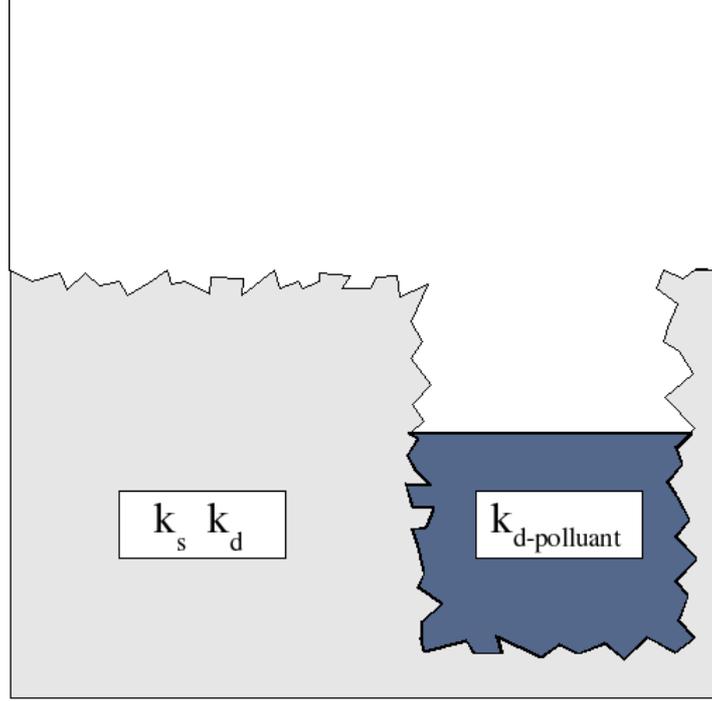


Fig. 2. Pore partially filled with water.

is approximated as a purely specular one (almost mirror-like behavior). Therefore, pore contribution to diffuse reflection is progressively replaced by a contribution to specular reflection due to water. This phenomenon is simulated using a relative filling time t_{fil} . The wet porous model becomes:

$$\begin{aligned}
 k_{d-poro-wet} &= k_d \cdot (1 - \alpha_{poro} \cdot G_p) \\
 &+ \left(k_d \cdot \alpha_{poro} \cdot G_p \cdot (1 - A_p) \right. \\
 &\left. + k_s \cdot (1 - A_p) \cdot \alpha_{poro} \cdot G_p \right) \cdot \left(1 - \frac{\Delta t}{t_{fil}} \right)
 \end{aligned} \tag{2}$$

$$k_{s-poro-wet} = k_s (1 - \alpha_{poro} \cdot G_p) + k_{s-water} \cdot \alpha_{poro} \cdot G_p \cdot \frac{\Delta t}{t_{fil}} \tag{3}$$

$k_{s-water}$ is the water specular coefficient. We add a new purely specular component to the specular term of the original model. When pore filling increases, the shader is

changed to account for the new formulas of $k_{s-poro-wet}$ and $k_{d-poro-wet}$. Parameters t_{fil} and Δt are explained in details in the next section. In order to increase realism, water specular color is taken from an environment map to simulate reflection on the porous water-filled surface portion.

3.3. Animating the model: drying process

3.3.1. The wet texture

To increase realism of rendering, we want to simulate common interactions implying wetting/ drying of surfaces. To this purpose, we add a texture to control our model. We call this texture "wet texture". It is a 2D gray scale texture mapped onto each model. We can extract from it a value and a position onto the surface. Gray scale gives a range from 0 (Black), meaning never wet during our simulation, to 1 (White) meaning firstly wet. This value is interpreted as a relative start time of wetting as explained later. This parameter helps us, in the real time context, to animate drying and wetting. The wetmap can be understood as the mean level of water trapped into the pore.

To compare our model with real photos, we proceed as follow. Using a real photo, we extract the position and shape of water splats on the model (for instance, bricks shown in figure 6(a)). This work is done externally and does not influence the model itself. Examples of extracted textures are shown in figure 3. This map is then only composed with binary information. In order to simulate drying from this photo, we add a simple gradient in the wet texture which permits to empirically extrapolate the drying phenomenon. We can observe that, in a drop, border dries first. We blend some circular gradient to add greyscale information to the wet texture. This helps us to simulate the drying of wet material. Furthermore, when the surface on the photo is entirely wet, the drying is more stochastic. However, concerning porous media, the way the material dries is directly linked with porosity. Water height in the pores is not uniform over the surface. Therefore, we create an empirical texture based on this observation. A greyscale Perlin noise is used as wet texture and this lead us to simulate this kind of drying. Thus, we can with this method simulate the drying of porous surface using photos of dry and wet material.

Furthermore, we simulate rain fall to show our model in another context. We calculate first the model's wet map. We achieve this task while computing a light map using Autodesk Maya in the following manner:

- We position an emissive plane on top of the mesh in the modeler.
- We texture the mesh as for classical 2D texture mapping.
- We compute the light map of the mesh lit by the emissive plane using Autodesk Maya.

During real-time rendering, drops falling onto the mesh are simulated. This specific

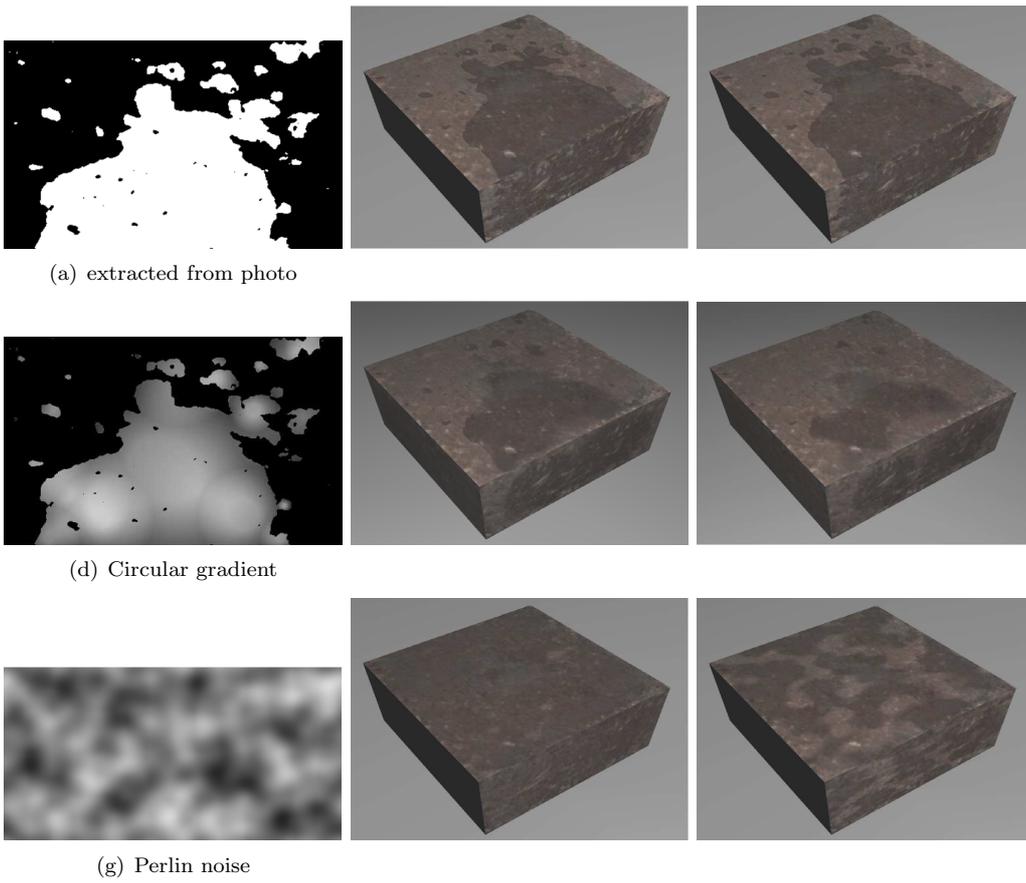


Fig. 3. Wet map extracted from photo 6(c)(left). Examples (right-middle) using the wet map

task is explained in the section4

3.3.2. Empirical time parameter

During the animation, we use an empiric relative simulation time t . As previously described, the wet map gives us a value (between 0 and 1) indicating when pores of the given pixel will begin to fill. This is the t_0 point. t_{fill} is linked to the given matter itself, and represents the average filling time of pores. However, we can not give a complete mathematical derivation of this parameter because it depends on many data (pluviometry, pore volume, Jurin's law). This parameter controls the smoothness of border between dry and wet areas. With a zero value, a straight border will appear because pores are filled instantaneously. With higher values, borders appear smoother. During our experimentations, we choose values between 0.10 and 0.50 (in respect with the original range [0-1] cf. table 1) for this parameter to have good-looking behavior. Consequently, values of Δt as used in the model can be summarized as follows with previously described nomenclature:

Δt	Value
0	$0 < t < t_0$
$t - t_0$	$t_0 < t < t_0 + t_{fill}$
t_{fill}	$t_0 + t_{fill} < t < 1$

Furthermore, we can now explain the three incident light contributions to our model. In the equation 2, non porous part of the surface will behave as the original model:

$$k_d \cdot (1 - \alpha_{poro} \cdot G_p)$$

$$k_s \cdot (1 - \alpha_{poro} \cdot G_p)$$

Porous part of the surface contribution:

$$k_d \cdot \alpha_{poro} \cdot G_p \cdot (1 - A_p) + k_s \cdot (1 - A_p) \cdot \alpha_{poro} \cdot G_p$$

will be modulated by $1 - \frac{\Delta t}{t_{fill}}$

and then will decrease when water fills the pore. Consequently, pore's water contribution, added in the specular coefficient $k_{s-poro-wet}$ (see eq. 3).

$$k_{s-water} \cdot \alpha_{poro} \cdot G_p$$

will increase modulated by $\frac{\Delta t}{t_{fill}}$.

4. Real-time implementation

Firstly, we have to choose a BRDF model that can be split into two independent parts: a diffuse component and a specular component. In our experimentations, we chose

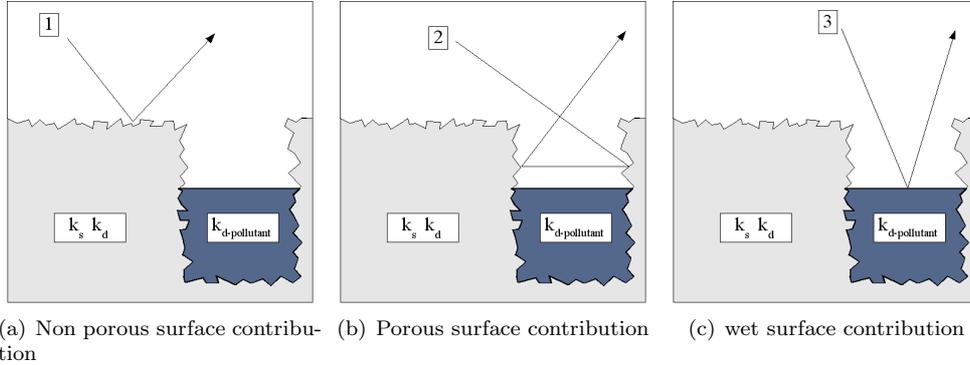


Fig. 4. The three incident light contributions to our model.

Blinn/Phong[1] as the base BRDF. This is mainly because it is one of the most widely used lighting models in real-time rendering but also because it is easy to implement: in fact, current hardware is specifically optimized to evaluate this reflectance model [11]. Secondly, we need to compute a wet map (section 3.3.1) to locate parts of the mesh that are likely to be wet. Then, the rendering step consists in:

1. Computing k_d and k_s components of the chosen BRDF (in our case: Blinn/Phong). This is done in the vertex shader stage of the graphics card. The computed k_s and k_d components are then interpolated along the triangle surface and used in the pixel shader.
2. Applying the BRDF post-process simulating porosity while using these parameters (cf. section 3.1). This task fully lies in the pixel shader stage of the graphics card.

5. Results

All our experimentations were driven using a NVIDIA GeForce 6800. The complexity of our method mainly depends on the number of pixels drawn. For a scene entirely covering a 1280x1024 screen, we get about 90 FPS. If the scene covers half the screen, frame rate increases around 300 FPS. We first compare our model with real photos. Figure 6(a) shows a photo with two dry bricks. The figure 6(b) shows the same bricks in real-time using the porous model described in the section 3.1. Water is applied onto the bricks. Figure 6(c) the results of this human interaction. We extract wet map using the photo (example shown in the figure 3). The scene is rendered using our model in real time 6(d).

Rainfall effects on cultural heritage can also be represented. The figure 7 shows a simulation of rain fall onto a bas-relief using the wet model and wet map generation described

in the section 3.3.1. Simulation starts from a dry and porous model and finishes with a complete wet model according to the wet map. Drops are stored into a texture which is another gray scale texture representing drops of water falling onto the model. It is computed while rendering lines or points in an offscreen buffer. These lines or points represent the impact of rain drops that come from the sky. The rgb value stored in this map is combined with the value stored in the wet map to obtain the final quantity of water for a given point of the surface. This texture uses the same parameterization that the wet map (i.e. same texture coordinates). It is only needed during rainfall simulation. In order to highlight the role of α_{poro} , the figure 5 presents a set of four pictures representing the same flowerpot at the same time. α_{poro} represents the percentage of surface covered by pores. When it increases, surface becomes darker and more specular. The water contribution to light reflection is increased by the great amount of surface pores.

To compare our model with Jensen's one, we choose to render a scene similar to the scene representing a stone on a sand beach (see [6]). Figure 8 represents our scene with a dry stone (8(a)) and with a wet stone (8(b)). We can deduce that our model permits to represent the same behavior of wet materials than the Jensen's model.

6. Conclusion and future works

In this paper, we have presented a model that permits to render wet materials in real-time. This model is very simple to handle and to implement. Moreover, it is based on physical observations concerning water absorption occurring into porous media. It permits to handle both the darkening of materials and the specular behavior increase using intuitive parameters. This model seems to be very useful in order to increase realism of numerous real-time scenes dealing with flow simulation. However, the model is not able to handle translucent effects observable on a wet paper sheet for example. This specific point is actually under investigation. Another way to extend this model concerns the "water saturation" of porous media. When pores are fully filled, water propagates onto the material as a thin layer, decreasing the influence of roughness and providing a specific mirror-like aspect. While this effect can be achieved (in first approximation) by a strong increase of the specular components, a more accurate model as to be presented, in particular when closed views need to be computed.

References

- 1977**
[1] James F. Blinn. Models of light reflection for computer synthesized pictures. In Proceedings of the 4th annual conference on Computer graphics and interactive techniques, pages 192-198. ACM Press.
- 1978**

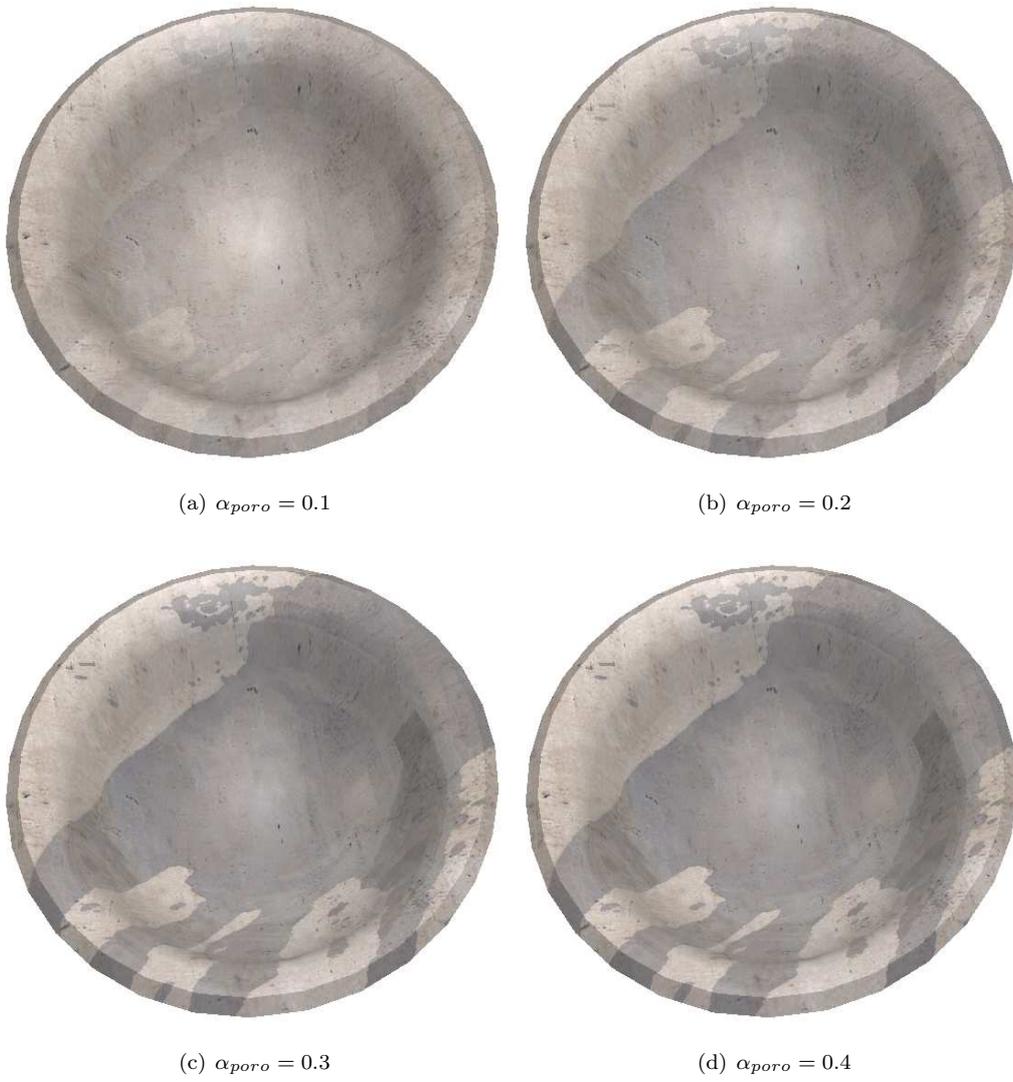


Fig. 5. Role of α_{poro} in the model

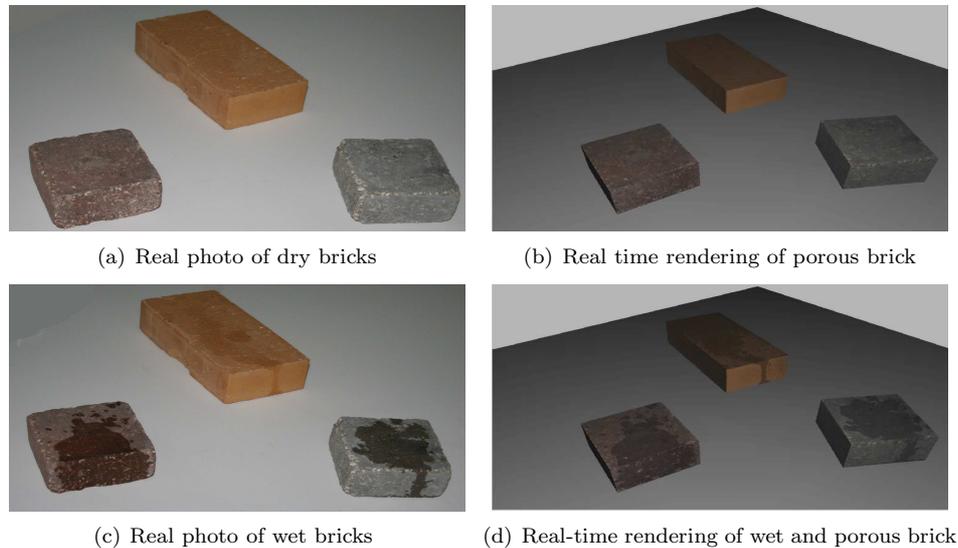


Fig. 6. Comparison of our model with real photos

- [2] James F. Blinn. Simulation of wrinkled surfaces. In Proceedings of the 5th annual conference on Computer graphics and interactive techniques, pages 286-292. ACM Press.
1990
- [3] C. J. Brinker and G. W. Scherer. Sol-gel science. Harcourt Brace and Company Publishers, San Diego, 1990.
1984
- [4] Robert L. Cook. Shade trees. In Proceedings of the 11th annual conference on Computer graphics and interactive techniques, pages 223-231. ACM Press.
1994
- [5] Andrew S. Glassner. Principles of Digital Image Synthesis. Morgan Kaufmann Publishers Inc.
1999
- [6] H.W. Jensen, J. Legakis, and J. Dorsey. Rendering of wet materials. In Eds. D. Lischinski and G. W. Larson, editors, Rendering Techniques V 99, pages 273 - 282.
2005
- [7] J. Lu, A. S. Georgiades, H. Rushmeier, J. Dorsey, and C. Xu. Synthesis of material drying history: Phenomenon modeling, transferring and rendering. Eurographics Workshop on Natural Phenomena, pages 9-16.
2005
- [8] Youquan Liu, Hongbin Zhu, Xuehui Liu, and Enhua Wu. Real-time simulation of physically based on-surface flow. The Visual Computer(Pacific Graphics 2005 issue).
2000
- [9] S. Merillou, J.-M. Dischler, and D. Ghazanfarpour. A BRDF post-process to integrate porosity on rendered surfaces. In IEEE Transaction on Visualization and Computer Graphics, volume 6, pages 306-318.
1990

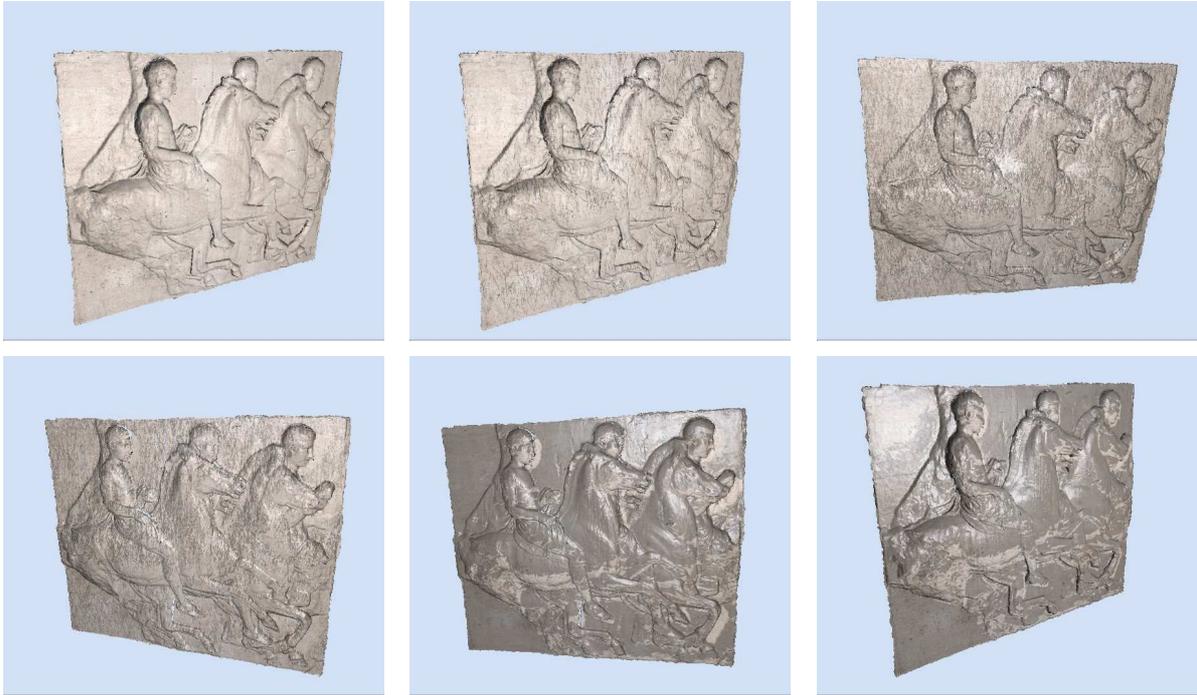


Fig. 7. Rainfall simulation on a bas relief

[10] Eihachiro Nakamae, Kazufumi Kaneda, Takashi Okamoto, and Tomoyuki Nishita. A lighting model aiming at drive simulators. SIGGRAPH Comput. Graph., 24(4):395-404.

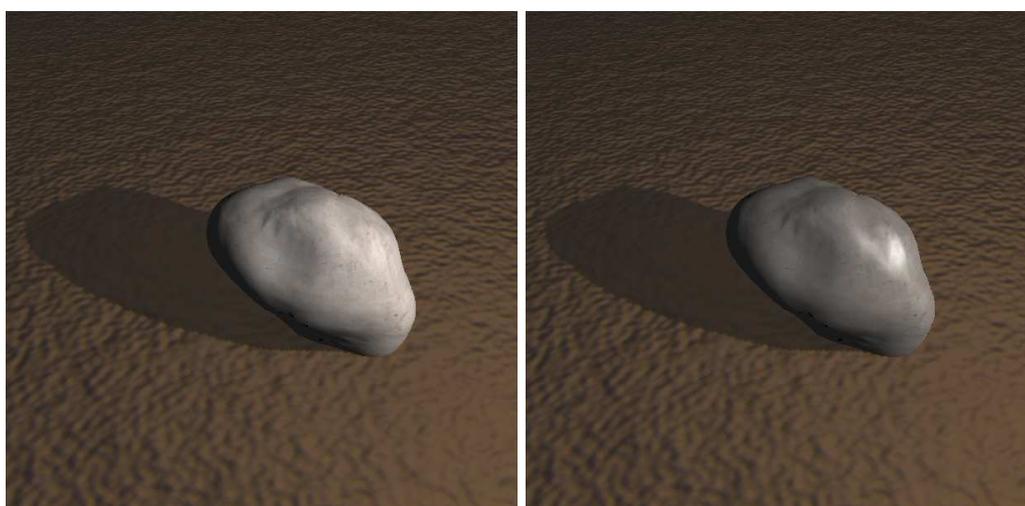
[11] Nvidia corporation <http://developer.nvidia.com>.

1986

[12] Patric P.D.: Artists and computers: a retrospective. IEEE CG&A, 6(8), 36-48.

1987

[13] Blake A., Zisserman A.: Visual Reconstruction. MIT Press, Cambridge, MA.



(a) dry stone

(b) wet stone

Fig. 8. A scene inspired from [6], showing a dry and a wet stone